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STUDY OF ETHYLENE OXIDE EFFECTS ON COMPONENTS

PART I. FINAL REPORT – PHASE II STUDY

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TRW *SYSTEMS*

ONE SPACE PARK · REDONDO BEACH. CALIFORNIA

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PART I

STUDY REPORT

A. SUMMARY OF COMPATIBILITY STUDY

As a result of the Study of Ethylene Oxide Effects on Components (Phase II) conducted by TRW Systems, it is concluded that it is possible to establish a high degree of confidence in the ability of a selected list of electronic component parts to withstand the effects of ethylene oxide sterilization procedures and subsequently to perform satisfactorily in planetary spacecraft electronic equipment such as Voyager.

To establish this confidence, a comprehensive test program is recommended, involving laboratory testing of a quantity of 9195 parts of 35 different types, representing all component types listed in the Tentative Voyager-Lander Parts List, which is largely the same as the list of Electronic Part Sterilization Candidates for Spacecraft Applications generated by Jet Propulsion Laboratory.

A hypothesis has been arrived at as a result of this study program for each of the component types recommended for testing, namely,

> Each of these parts is fully capable of withstanding the full effects of combined ethylene oxide and heat sterilization procedures, as specified, without degradation affecting physical or electrical performance under anticipated conditions of the Voyager mission.

To verify these hypotheses, it is considered essential to perform a series of carefully controlled laboratory tests and to arrive at sound engineering judgments based upon statistical analysis of the test data.

1. Sterilization Problem

Ethylene oxide, the sterilant designated for use on planetary spacecraft equipment under specified procedures, owes its effectiveness to its ability to penetrate and attack viable organisms. The same properties which result in effectiveness of ethylene oxide as a sterilant, however, are potentially degrading to both organic and inorganic substances used in fabrication of electronic parts. Inasmuch as component

parts of space electronic equipment are required to exhibit high stability and high reliability performance, even slight degradation of sensitive characteristics is of utmost concern. All possible modes of potential degradation of component parts must therefore be considered, including the long term effects of residual quantities of the sterilant mixture, the effects of subsequent conditioning, methods of application of the sterilant, temperature, moisture, pressure, concentration, and related factors. For the purposes of this study, only the formulation consisting of 12% ethylene oxide and 88% Freon 12, applied under specified conditions are considered.

Since ethylene oxide definitely is corrosive on a long list of materials, many of which are used in the fabrication of electronic parts, hazards must be supposed to exist in the application of ethylene oxide to space electronic equipment as a sterilant, even in an attenuated gaseous form. It appears possible, however, to select components containing materials not affected by ethylene oxide and, by controlled testing of the selected components, to justify safe use of these parts in space electronic equipment. This justification can be provided only by expenditure of considerable effort. The effort involved in launching planetary space missions, however, requires that confidence in components be established beyond a reasonable doubt.

The available information in existing technical literature containing test data relating to component part performance following exposure to ethylene oxide, although significant, is insufficient for a judgment of this nature. Most of the earlier work has been preliminary evaluation testing conducted on individual specimens, rather than statistically significant quantities, and under less rigorous conditions than presently specified. On the basis of presently available information, it is only possible to hypothesize satisfactory performance of components, not to establish absence of degradation as a positive conclusion.

2. Recommended Solutions to Problem

To establish conclusively the immunity from physical and electrical degradation of component parts exposed to ethylene oxide sterilization, a thorough engineering evaluation program is required.

The study phase of the program, which is now completed, has resulted in a thorough evaluation of the sterilization problem as related to electronic component parts. Information has been compiled in tabular form on the results of prior tests of electronic parts following ethylene oxide exposure. Information also has been gathered on efforts of previous researchers on the results of testing materials under similar exposure. In this manner, a thorough familiarity has been obtained with degradation mechanisms, susceptible materials, and parameters affected.

A list of electronic component parts candidates for use in the Voyager-Lander has been prepared on the basis of anticipated usage in electronic equipment. Preliminary examination has been made of the constituent materials to assure the likelihood of immunity of these parts to attack by the ethylene oxide sterilant. For each candidate part type, it is therefore possible to hypothesize immunity, subject to verification testing.

The next phase of the program (see Part II, Recommended Test Program) is the verification testing of the 35 part types under controlled conditions. The first step would be the electrical screening and stabilization of sample parts in order to assure validity of final test data by minimizing drift of electrical characteristics. A second step in the test phase is pilot testing of a limited number of part types, both control samples and samples exposed to specification ethylene oxide procedures. Pilot tests will verify experimental procedure and permit selection of statistical test method. Long term tests will be conducted as a third step in the test phase to simulate the actual Voyager mission profile for both control and specification exposure samples. A fourth step is the statistical analysis of test data, largely by use of computer techniques.

A considerable portion of the planning for the test phase has been accomplished as a part of the present study program. Part types have been selected. For each part type, the parameters to be measured to indicate degradation have been chosen, the potential degradation mechanisms have been outlined, the pre-testing stabilization measures have been designated, the test equipment of the required accuracy has

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been selected, and size of test samples determined. For the overall test phase, statistical design and analysis methods are outlined.

The results of the test phase will provide conclusive engineering confidence in the immunity of component parts from degradation by ethylene oxide sterilization exposure, thus permitting successful development, design, fabrication, and launching of Voyager equipment.

Possible use of an orbiting Environmental Research Satellite is suggested for extended life testing of component parts as an additional measure to establish complete confidence in the ability of parts to withstand exposure to sterilization and subsequently survive space environment. This could be accomplished as Phase IV of the present program. Cost effectiveness studies indicate that this type of orbital testing is more economical than long-term space environmental simulation testing. These satellites (see Part III) are presently available in several designs, weighing from 1.5 to 9 pounds, for piggyback launching from large primary mission vehicles. Several are presently in orbit. For a program effort as extensive and significant as the Voyager, use of such an Environmental Research Satellite might dispel all remaining doubt regarding effects of ethylene oxide sterilization on performance of electronic equipment in space.

B. METHOD OF INVESTIGATION

A basic requirement imposed upon exploration of Mars is that the probability of contaminating the planet by viable organisms from the earth must be less than one in ten thousand. Entire landing vehicles must therefore be capable of being sterilized without degradation.

As a result of studies at the Jet Propulsion Laboratory, sterilization and decontamination procedures have been developed. Qualification requirements to prove suitability of space vehicle components for these procedures are detailed in JPL Specification VOL-50503-ETS, "Environmental Specification, Voyager Capsule Flight Equipment, Type Approval and Flight Acceptance Test Procedures for Heat Sterilization and Ethylene Oxide Decontamination Environments," dated 12 January 1966.

Electronic parts will be subjected to the requirements of the type approval environmental specification. Under JPL direction, a list of parts capable of withstanding the heat sterilization requirements has been compiled into JPL Specification ZPP-2010-SPL-B, "Electronic Part Sterilization Candidates for Spacecraft Application," dated 1 December 1965.

All of the parts on this list have either been qualified to the heat requirements of JPL Specification VOL-50503-ETS or are in the process of being qualified. These parts have not, however, been proved capable of withstanding the ethylene oxide decontamination procedures.

A program to establish conclusively electronic part immunity to ethylene oxide decontaminants is now underway as described in JPL Specification SW1013, "General Requirements, Sterilization Test Program, Investigation of Ethylene Oxide Effects on Component Parts," dated 1 October 1965.

Briefly, the program consists of three (or possibly four) phases as follows:

Phase I. A solicitation phase, in which qualified contractors have been invited to bid on Phase II.

Phase II. A literature search to gather existing information and plan Phase III.

Phase III. A testing program to verify conclusively whether or not there is a degradation problem when decontaminating electronic parts.

Phase IV. A follow-on program to solve problems arising during Phase III. This program may not be necessary.

Under contract to JPL, TRW Systems has been engaged in performance of Phase II of this program. General procedure has been:

1. Gathering all available information regarding ethylene oxide sterilants.

2. Generating a tentative Voyager-Lander Parts List.

3. Forming a hypothesis regarding the susceptibility of each part on this list.

The susceptibility hypothesis was drawn using:

1. The findings of the information search.

2. Known physical and chemical reactions.

3. Extensive previous TRW testing and application experience with these parts, or parts having essentially identical constituent and processing materials and processes.

Although the investigation has covered information of all types on ethylene oxide sterilants, primary emphasis was directed toward information regarding the effects on electronic parts. Biological effectiveness was treated as incidental, as directed by the work statement. The effects of sterilants on basic materials, although not of primary interest, was used in drawing the hypothesis regarding parts having no previous sterilant testing history.

All ethylene oxide sterilants have been included in this investigation. It must be emphasized, however, that the decontaminant of Specification VOL-50503-ETS is a mixture of 88% Freon 12 and 12% ethylene oxide at 50°C, 50% relative humidity, and a concentration of 600 milligrams of ethylene oxide per liter of gaseous atmosphere. None of the previous tests reported in the literature fully meets these requirements, having

generally accomplished testing under less stringent conditions. This study has extrapolated the findings of previous test data to meet present JPL requirements and the test program, which is proposed as a result of this study, also meets all of the conditions of Specification VOL-50503-ETS.

A search was made of the technical literature for previous experience with ethylene oxide-Freon 12 gas sterilant on components and materials. Specifically, the following information was sought:

1. Component types and materials degraded by exposure to the gas mixture.

2. How they are degraded.

3. If the gas entered a non-hermetically sealed part, how residual would it be, and what long term effects would result.

4. What effect on material and part compatibility would result from varying the ethylene oxide concentration.

5. Does heat sterilization following gas exposure aggravate the effects, or vice versa.

Although this is a parts study, material compatibility data was sought also, since the effects of ethylene oxide on parts are essentially effects on the materials of which they are constructed. Understanding the degradation mode of a part and intelligently designing an experiment to test this depends on an understanding of the ethylene oxide and material interaction.

The search also endeavored to obtain heat sterilization test data on parts for refinement of the tentative parts list. The data were used in developing the preliminary Voyager parts list, discussed in this report.

The investigation encompassed searches through NASA STAR, DDC, and IDEP documents, communication with JPL and NASA centers, NASA contractors, ethylene oxide users, and manufacturers. The literature from 1962 to the present was examined. A comprehensive survey report prepared in 1962 was used to scrutinize data generated prior to that date.

C. ETHYLENE OXIDE DEGRADATION EFFECTS

1. Electronic Components

All reported test results on the compatibility of ethylene oxide with component parts (Table I) are for tests performed using lower ethylene oxide concentration and exposure temperatures than specified in JPL Specification VOL-50503-ETS. In most instances, concentrations were 400 to 500 milligrams per liter of ethylene oxide rather than 600 milligrams per liter, and 100 to 104°F instead of 122°F. Exposure times have been considerably less also. Since reaction rates are directly proportional to concentration and temperature, and the extent of a reaction is time dependent, these tests represent minimum exposure conditions. Any degradation brought about by these exposures would tend to be intensified by the more severe VOL-50503-ETS conditions.

In all previous testing, the sterilant gas exposure has been demonstrated to have very minor effects, if any, on electronic parts. Tests have been performed on: (1) resistors, including wirewound, carbon composition, metal and carbon film; (2) capacitors, including mica, paper, ceramic, and tantalum; (3) transistors; (4) diodes; (5) connectors; and (6) RF coils.

Some minor electrical changes have been noted in tantalum capacitors. Two capacitors produced by General Electric and two manufactured by Sprague Electric have shown small increases in measured leakage current. However, the final values of leakage currents have been well below specifications limits.[1,2] Interpretation of the significance of these changes is clouded by the fact that similar changes can be observed in tantalum capacitors under other types of environmental exposure. Leakage current variations can also be detected when such a capacitor is subjected to several charge-discharge cycles.

A more pertinent test than currently employed to determine the effects of ETO exposure on tantalum capacitors would be the continuous monitoring of leakage current during ETO exposure after the capacitor has been maintained in a charged condition for several hours to effect stabilization. Any radical increase could then be attributed to the ETO.

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TABLE I. COMPATIBILITY OF ELECTRONIC COMPONENTS WITH ETHYLENE OXIDE EXPOSURE

	Com-patible	Properties Measured	ETO Exposure (Note 1)	Data Source
SOLAR CELLS				
Hoffman	Note 2	Solar	24 hrs, 100°F	Refer-
Int'l Rectifier	Note 3	power	30 to 50% RH	ence 4
RESISTORS				
Wirewound, power, Sage S2W	Yes			
Carbon comp., Allen Bradley TR	Yes			
Carbon comp., Allen Bradley CB	Yes			
Metal film, Allen Bradley CAH	Yes			
Carbon film, Mep. Co. R-170N	Note 4			
Metal film, Int'l Resis. Corp. XLT-A	Yes			
Carbon film, Texas Inst. CGY4	Yes			
Carbon film, Victoreen RX high meg.	Yes			
Wirewound, accurate, Ultronix 205A	Yes	Resistance	24 hrs, 100°F	Refer-
Metal film, Weston 9849-4	Yes		30 to 50% RH	ence 2
Metal film, Weston 9850-2	Yes			
Metal film, Daven RN 70C	Yes			
Wirewound, power, Dale ARS-2	Yes			
Metal film, Int'l Resis. Corp. MEC	Yes			
Thermistor, Westinghouse 802-05	Yes			
Carbon film, Electra DCM 1/2	Yes			
Wirewound, power, Calif. Resis. SAV	Yes			
Carbon film, Sprague RN 60B	Yes			
Metal film, American Comp. C1	Yes			
Sensistor, Texas Inst. TM 1/4	Yes			
Metal film, Resistance Prod. WFH	Yes			
Thermistor, Victory Eng.	Yes			
Texas Inst. RN 60	Yes			
Int'l Res. Corp. RN 65	Yes		36 hrs, 104°F	Refer-
Int'l Res. Corp EM	Yes	Resistance	30 to 90% RH	ence 1
Composition, Allen Bradley	Yes			
Dale GRS-1A	Yes			
Carbon, 330 ohms	Yes			
Carbon, 390 ohms	Yes			
Carbon, 3300 ohms	Yes	Resistance	18 hrs, r.t.	Refer-
Carbon, 13K	Yes	Surface	~30% RH	ence 3
Carbon, 15K	Yes	conduc-	(Note 5)	
Carbon, 1M	Yes	tivity		
Wirewound, 0.5M	Yes			
Wirewound, 1750 ohms	Yes			
TRIMPOTS				
Bourns 3051C	Yes	Resistance	36 hrs, 104°F	Refer-
Bourns 224L-1-203	Yes	Resistance	30 to 90% RH	ence 1
CAPACITORS				
Electrolytic, 4 mfd	Yes			
Electrolytic, 10 mfd	Yes			
Mica, 0.0001 mfd	Yes			
Mica, 0.00026 mfd	Yes	Capacitance	18 hrs, r.t.	Refer-
Mica, 0.004 mfd	Yes	Surface	~30% RH	ence 3
Paper, 0.1 mfd	Yes	conduc-	(Note 6)	
Paper, 0.005 mfd	Yes	tivity		
Paper, 0.004 mfd	Yes			
Paper, 0.001 mfd	Yes			
Paper, 0.03 mfd	Yes			
Mica, El Menco DM	Yes			
Paper, Sprague 196P	Yes	Capacitance		
Paper-mylar, metallized, Sprague 118P	Yes	Dissipation	24 hrs, 100°F	Refer-
Paper, Gudeman XHF	Yes	factor	30 to 50% RH	ence 2
Solid tantalum, Sprague 150D	Note 7	Leakage		
Solid tantalum, Kemet KH50	Yes	current		
Liquid tantalum, Mallory, XTM	Yes			

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TABLE I. COMPATIBILITY OF ELECTRONIC COMPONENTS
WITH ETHYLENE OXIDE EXPOSURE (Continued)

	Com-patible	Properties Measured	ETO Exposure (Note 1)	Data Source
CAPACITORS (Continued)				
Tantalum, G.E. 5K104AA2	Note 8			
Tantalum, G.E. TK128G3	Yes			
Tantalum, Sprague 350D	Yes			
Tantalum, Sprague 196P	Yes			
Ceramic, Vitramon CY	Yes	Capacitance Dissipation factor Leakage current Insulation resistance	36 hrs, 104°F 35 to 90% RH	Reference 1
Ceramic, Vitramon CY12C	Yes			
Ceramic, Vitramon VK	Yew			
Disc, Centralab (0.02 µfd)	Yes			
Glass, Corning CYFR 30	Yes			
Ceramic, Aerovox HMC80	Yes			
Goodall 617G	Yes			
San Fernando CK	Yes			
San Fernando 98	Yes			
Paper, Electron Prod. EP	Yes			
Maida 287L	Yes			
MOTOR				
Direct current stepper motor, Hughes HUG X988350	Yes	Stall current Torque Insulation resistance	24 hrs, 100°F 35 to 50% RH	Reference 2
DIODES				
1N485, Fairchild	Yes			
MC 1291, Micro Semicond.	Yes			
1N916, Texas Inst.	Yes			
1N3030, Motorola Zener	Yes	Reverse leakage current	36 hrs, 104°F 35 to 90% RH	Reference 1
1N3022, Motorola Zener	Yes			
1N2615, Motorola	Yes			
1N645, PSI	Yes			
1N759A, PSI	Yes			
1N746A, PSI	Yes			
Zener, PSI PS 4642	Yes			
TRANSISTORS				
2N491B, G.E.	Yes			
FE 200, Amelco	Yes			
2N2497, T.I.	Yes			
2N2608, Siliconix	Yes			
2N892, Solid State Prod.	Yes			
2N943, PNP, Sperry	Yes			
2N329A, PNP, Sperry	Yes			
2N930, NPN, Texas Inst.	Yes			
2N1050B, NPN, Texas Inst.	Yes	h_{FE}	36 hrs, 104°F 35 to 90% RH	Reference 1
2N956, NPN, Texas Inst.	Yes	I_{CBO}		
2N2432, NPN, Texas Inst.	Yes			
2N2150, NPN, Texas Inst.	Yes			
2N2222, NPN, Motorola	Yes			
2N2331, NPN, Motorola	Yes			
2N1893, NPN, Fairchild	Yes			
2N708, NPN, Fairchild	Yes			
2N995, PNP, Fairchild	Yes			
2N2060, NPN, Diff. Amp.	Yes			
2N417 Raytheon	Yes			
2N332, Texas Inst.	Yes	Electrical perform-ance parameters	18 hrs, r.t. ~30% RH	Reference 3
2N327, Raytheon	Yes			
ST401	Yes			
2N173, Delco	Note 9			
2N278, Delco	Note 9			
RF COILS				
Delevan Series 1537	Yes	Inductance, Q Capacitance Resistance	24 hrs, 100°F 30 to 50% RH	Reference 2
Essex Wee-ductor	Yes			

TABLE I. COMPATIBILITY OF ELECTRONIC COMPONENTS WITH ETHYLENE OXIDE EXPOSURE (Continued)

	Com-patible	Properties Measured	ETO Exposure (Note 1)	Data Source
CONNECTORS				
Microdot Series 43	Note 10		2 cycles, 24 hrs 100°F 30 to 50% RH	
Microdot Series 43 with silicone grommets rem	Yes	Dielectric strength Insulation resistance		Reference 2
Microdot Series 52	Yes			
General RF Fitting 822	Yes		24 hrs, 100°F 30 to 50% RH	
Continental Connector CS Series	Yes			
Cannon DCM-37P-NMI	Yes			
Cannon DCM-37S-NMI	Yes			

NOTES:

1. 12% ethylene oxide and 88% Freon 12 at one atmosphere
2. 8% degradation of solar power
3. Compatible with 5% degradation of solar power
4. Compatible, with small increase in resistance
5. Properties measured after post exposure to 100°F, 90% RH for 96 hours
6. Properties measured after post exposure to 100°F, 90% RH for 96 hours
7. Compatible, with very small increase in leakage current
8. Compatible, with increase in measured leakage current, but not outside specification limits
9. Compatible, with slight increase in beta
10. Compatible with small decrease in insulation resistance

Sample sizes for all tests varied from 1 to 7 specimens

Among resistors, only some carbon resistors and a Bourns Trimpot have demonstrated minor electrical changes.[1,2] The changes are not significant since they could occur just during shelf aging of the resistors.

Semiconductor devices have also exhibited excellent stability under ETO exposure. In one study, two transistors have suffered slight decreases in beta after exposure.[3] Solar cells of two manufacturers have been reported to undergo small power degradations as the result of another study.[4] Many other transistors and diodes have demonstrated no significant changes in any measured properties, which included reverse current and breakdown voltage, collector-to-emitter voltage, collector current, base current, collector-to-base voltage (emitter open), emitter current, and collector cutoff current (emitter open).[1,3]

Microdot Series 43 connectors containing silicone grommets have shown no deterioration in dielectric strength but suffered decrease in insulation resistance after sterilant exposure. The connectors were subjected to two 24-hour exposures to the gas mixture, followed each time by electrical property measurements. The decrease in insulation resistance after the second exposure was greater than after the first, although all values were within specification requirements. When the silicone grommets were removed prior to exposure, insulation resistance was unaffected.[2]

In a study of the feasibility of executing electronic assemblage in a sterile glove box atmosphere, it was reported that soldering of resistor and capacitor leads to printed circuit cards by hand and dip methods were conducted in ETO atmosphere at room temperature and approximately 30% relative humidity after a minimum of 48-hours soak in the gas atmosphere.[5] Any changes experienced in resistance were considered to be minor and within the tolerances of the instruments used. Most of the changes in values appeared in the second decimal place. Changes were both on the plus and minus sides. Photomicrographic solder joint analyses did not show any differences between the solder joint made in air and those made in ETO atmosphere.

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The data obtained in these previous tests are not reproduced in this document because (1) the specific parts tested were not completely defined, and (2) all of the data indicated the same trend. Analysis of the data resulted in an interesting observation. An analysis of variance, the statistical technique that permits comparison of variation in controlled factors with the variation in random uncontrolled factors, indicated that changing the assembly atmosphere affected certain components. The validity of random variation measurements was in doubt, however, because of the abnormally low F ratios* for succession of testing at certain test points. An analysis of means and ranges, also performed on the data, in which the means of each test point for the boards assembled in each atmosphere were plotted against the different stages of testing, showed that the general data pattern was followed regardless of the atmosphere in which the boards were assembled. The ranges of readings in cells exhibited no pattern that was unique and repeatable. Conclusions from these analyses were that each circuit tended to be unique but did not change appreciably from the breadboard configuration in ordinary laboratory atmosphere to manufactured condition in ETO, sterile air, or sterile nitrogen following an ETO soak period.

2. Materials

Compatibility information on materials is important in predicting possible effects of the sterilant gas on components composed of these materials. A large amount of information on material compatibility at 100°F with a 24-hour exposure was obtained from tests conducted by Willard.[2,4] In these tests appropriate physical, mechanical, and electrical properties were measured on the materials before and after gas exposure (Table II). Specification requirements were used in guidelines in determining compatibilities.

Some material changes observed were slight crazing of polystyrene, lightening in color of mylar recorder tape, a small increase in weight and decrease in volume of Lexan, formation of an oily material upon repeated exposure of DC-4 silicone, and some deterioration in

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* F ratio = variance alloted to each criterion of classification compared with random variance

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TABLE II. COMPATIBILITY OF MATERIALS WITH ETHYLENE OXIDE EXPOSURE

	Com-patible	Effects	Data Source*
ADHESIVES			
RTV 731 silicone	Yes	Low initial shear strength decreased 19%; can only be used where loads are low	4
FM 1000 epoxy polyamide	Yes		4
Epoxylite 5302 epoxy	Yes	17% shear strength decrease	4
Epibond 104 epoxy	Yes	12% shear strength decrease	4
Eccobond 45 LV epoxy	Yes	8% shear strength decrease	4
PLASTICS			
Lexan	Yes	3.3% weight increase	2
Kel-F	Yes		2
Polystyrene	Yes	.	4
POTTING AND ENCAPSULATING RESINS			
Stycast 2651/cat. 11 epoxy	Yes	Percent dissipation factor increased from 0.165 to 1.51.	23
Eccoseal W 19/cat. 11 epoxy	Yes	Dielectric constant increased from 4.50 to 4.65.	23
Stycast 1090/cat. 11 epoxy	Yes		4
Epon 826 amine cured	Yes		4
Epon 826 anhydride cured	Yes		4
Epon 828 amine cured	Yes		4
Epon 828 anhydride cured	Yes		4
DC 881 silicone	Yes	Dielectric constant increased from 2.97 to 3.23	2
ELASTOMERS AND RUBBERS			
Viton A, Linear 8250-85	Yes	8% tensile strength decrease.	2
Neoprene W, Parco 363-70	Yes	16% tensile strength decrease 20% ultimate elongation decrease	4
LS-53 Stillman TH1057	Yes	18% tensile strength decrease 18% ultimate elongation decrease	4
Buna N, Precision 758-70	Yes	14% ultimate elongation decrease	4
AMS 3302	Yes		4
METALS AND METAL COATINGS			
MIL-A-8625 Type I anodized aluminum	Yes		4
MIL-A-8625 Type II anodized aluminum	Yes		2,4
Dri-lube 6	Yes		4
Dow 17 light, Dow 17 heavy	Yes		4
AZ31B magnesium	Yes		4
DU lead teflon coating	Yes		4
Rokide	Yes		2
B3506-41-3 coating	Yes		2
CRYSTALS - Sodium chloride	Yes		2
GREASE - DC 4	Yes	Repeated exposures cause formation of an oily material	4

* Figures refer to references listed at the end of this report

electrical properties of potting and encapsulating resins . Among these resins were DC-881, Eccoseal W-19 and Stycast 2651.

The data on the potting and encapsulating resins are particularly pertinent since these materials are frequently used in electronic systems. Epoxies, to which class Eccoseal W-19, Epon 828, and Stycast 2651 belong, are used extensively in the manufacture of electronic components. Silicones, to which class DC-881 and DC-4 belong, have been used as protective coatings for transistor junctions but evidence indicates this usage is decreasing. A detailed comparison of compatibility data and manufacturing materials and processes is certainly warranted by the results of these investigations.

Changes were experienced with adhesives and elastomeric materials. All adhesives tested, which included silicones and epoxies, exhibited decreases in shear strength after exposure. These decreases did not degrade the materials for structural applications, but do point out the susceptibility of epoxies and silicones to sterilant gas. Although previous test have not evidenced gross failures of electronic components due of ETO exposure, long term deterioration, with lowered reliability, may result from relatively minor but significant changes in materials. Viton A, neoprene, fluorosilicone, and buna N elastomers have exhibited decreases of tensile strength and ultimate elongation which, although not serious in themselves, are significant.

Many reactions to ETO exposure appear to be due to solubility of ethylene oxide and/or Freon 12 in materials. [4,5,6,8] An observation supporting this hypothesis has been that H film has decreased 50% in tensile strength after ETO exposure, but upon subsequent exposure to heat sterilization, its tensile strength recovered to only an 18% loss.

Changes in volume have been observed on many plastic materials exposed to ETO (Table III). Phenolic laminates swelled during exposures to two 24-hour periods at $104°F$ in the sterilant gas atmosphere. Ensuing heat exposure reduced or even reversed the process. Among other materials tested, Micarta H-5834 exhibited the largest volume change with an increase of 5%. Heat exposure reduced this to 3.7%. [4,5] These phenomena also indicate solubility rather than reaction of ethylene oxide.

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TABLE III. COMPATIBILITY OF SELECTED POLYMERIC MATERIALS WITH ETHYLENE OXIDE*

	Com-patible	Effects
AMS 3303/60	Yes	Small hardness increase Hardness increases greater in Series I exposure than in Series II exposure 13.4% tensile strength decrease after Series II exposure
Epon 828/Z	Yes	Small decrease in hardness
H-Film (polyimide)	No	Compatible with Series II exposure with 18% tensile strength decrease Not compatible with Series I exposure with 50% tensile strength decrease
Epoxy laminate MIL-P-13949	Yes	2% hardness increase after Series II exposure
LS-53/70 fluorosilicone	Yes	
Micarta H-2497	Yes	5% volume increase after two 24-hour ETO exposures at 104°F 3.7% volume increase after subsequent heat treatment
RTV11 silicone	Yes	Small hardness increase after Series I exposure, Steps 1 and 2
RTV60 silicone	Yes	Small hardness increase after Series I exposure, Steps 1 and 2
RTV615 silicone	Yes	4% hardness increase after Series I exposure, Steps 1 and 2
RTV881 silicone	Yes	1% hardness decrease after Series I exposure, Steps 1 and 2
Silgard 182 silicone	Yes	
Stycast 1095/11 epoxy	Yes	Small decrease in weight and hardness after Series II exposure
Stycast 2651/11 epoxy	Yes	Small decrease in weight and hardness after Series II exposure
Tedlar 200, Type 30B White	Yes	
Parker Seal 2-218-S417-7 silicone	Yes	
Hadbar 4000-80 silicone	Yes	Small hardness decrease after Series I, Step 1; hardness increase after Series II, Step 2 and further increases after Step 3
Hadbar 7000-80 silicone	Yes	Small hardness decrease after Series I, Step 1; hardness increase after Series II, Step 2 and further increases after Step 3; 15% tensile strength decrease after Series II

Conditions of Exposure

    Series I (heat followed by two ETO exposures)
        Step 1. Three 36 hour cycles in nitrogen atmosphere at 145°C
        Step 2. 24 hours in 12% ETO-88% Freon 12 at 74°F, 30 to 50% RH
        Step 3. 24 hours in 12% ETO-88% Freon 12 at 104°F, 30 to 50% RH
    Series II (two ETO exposures followed by heat)
        Step 1. 24 hours in 12% ETO-88% Freon 12 at 74°F, 30 to 50% RH
        Step 2. 24 hours in 12% ETO-88% Freon 12 at 104°F, 30 to 50% RH
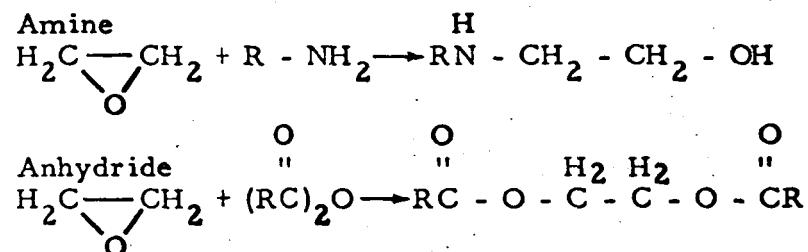   Step 3. Three 36 hour cycles in nitrogen atmosphere at 145°C

*Rydelek, R., "Study of the Effects of Ethylene Oxide-Freon 12 Upon Properties of Polymers and Metallic Surface," HAC P-65-57, JPL Contract 951003, Interim Status Report, Oct. 1, 1964 through April 30, 1965.

When a room temperature curing silicone was exposed to ETO atmosphere, 4% of the ethylene oxide was absorbed by the material. Upon vacuum treatment the residue of ethylene oxide in the material was reduced to less than 1%.[6] This could be indicative of both solubility and reaction of ethylene oxide, as the reaction could have produced materials whose vapor pressures were high enough to cause them to outgas in the vacuum environment. With residual chlorosilanes in a silicone polymer, the following reaction with ethylene oxide is possible:

$$- Si\ Cl + H_2C \overset{}{\underset{O}{\diagdown\diagup}} CH_2 \longrightarrow -Si - O - CH_2CH_2Cl$$
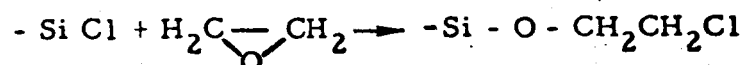
This possibility is substantiated by the fact that sterilant gas exposure followed by heat has been more detrimental to silicone than heat followed by gas exposure

Epoxy compounds absorbed a lesser amount of gas but showed a more pronounced change in properties than silicones.[8] Physical absorption and chemical reaction are suggested here. Ethylene oxide, having the same epoxide functional group as epoxy compounds, reacts with amines and anhydrides, which may be present as residual curing agents in epoxy resin systems. The following reactions with amine and anhydride are possible:

$$\text{Amine}\qquad\qquad H$$
$$H_2C \overset{}{\underset{O}{\diagdown\diagup}} CH_2 + R - NH_2 \longrightarrow RN - CH_2 - CH_2 - OH$$

$$\text{Anhydride}\qquad \overset{O}{\overset{\|}{}} \qquad \overset{O}{\overset{\|}{}} \qquad H_2\ H_2 \qquad \overset{O}{\overset{\|}{}}$$
$$H_2C \overset{}{\underset{O}{\diagdown\diagup}} CH_2 + (RC)_2O \longrightarrow RC - O - C - C - O - CR$$

It appears that where only physical sorption of ethylene oxide is involved, heat reverses the degradation of materials; when chemical reaction is possible, heat cycling following gas exposure aggravates the degradation.

Another interaction between ETO and materials which must be considered in a parts compatibility evaluation is permeability of materials to one or both components of the gas mixture. Ethylene oxide, a smaller and more polar molecule than Freon 12, can preferentially penetrate many films, effecting a separation of the two gases with the attend-

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ant danger of localized conditions of high ethylene oxide concentrations. Such a condition inside an electronic component may contribute to long-term deterioration. Dick and Feazel have measured the permeability (Table IV) of some plastic films to ethylene oxide.[9]

Accelerated testing by increasing the concentration of ethylene oxide, the more reactive component of the sterilant mixture, is a consideration for an experimental design for reliability testing. Data tabulated in a 1962 literature search[3] show differences in compatibility of materials with pure liquid ethylene oxide and two ethylene oxide gas sterilant mixtures (Table V). Most plastics and resins, as shown in Table V, are compatible with 12% ethylene oxide -88% Freon 12 and 10% ethylene oxide -90% carbon dioxide mixtures, whereas many are attacked by 100% liquid ethylene oxide. Also, anodized aluminum is noted as incompatible with liquid ethylene oxide because it promotes rapid polymerization of the chemical; however, a more recent test program using 12% ethylene oxide -88% Freon 12 demonstrates no reaction.[2]

Some chemicals which react with ethylene oxide are listed in Table VI. Most of the reactions involve opening of the epoxide ring and additions to the released carbon and oxygen bonds. Reactions with acids, halides, metal oxides, and bases are favored.[3]

Freon 12 (CCl_2F_2), the more inert component of the sterilant mixture, reacts with some materials only at elevated temperatures. Such materials are glass above 400°C, with which it reacts to form silicon tetrachloride and carbon dioxide, and some metals which act as catalysts for decomposition of the compound. The tendency of metals to promote thermal decomposition is in the following general order:

<u>Least decomposition</u>   Inconel
18-8 stainless steel
nickel
copper
1340 steel
aluminum
bronze
brass
<u>Most decomposition</u>   silver

At room temperature, Freon 12 dissolves oils, swells elastomers slightly, and causes crazing of polystyrene and methacrylate polymers after long exposures.[3]

TABLE IV. PERMEABILITY OF PLASTIC FILMS TO ETHYLENE OXIDE*

Film	Film Thickness (inches)	Permeability [a]
Cellophane 300 PT62	0.0009	0.00[d]
Polyvinyl alcohol	0.0037	0.00[d]
Polyester polyethylene terephthalate	0.001	0.00[d]
Vinyl and vinylidene plastics		
Polyvinyl chloride-nitrile rubber blend	0.0022	1.0
Polyvinylidene chloride	0.001	0.1
Polyvinylidene chloride blend	0.0011	0.6
Polyvinyl chloride	0.0011	2.0
Polyethylene	0.0014	0.35
	0.0019	0.35
	0.0024	0.33
Ethylcellulose[b]	0.003	3.9
Ethylhydroxyethylcellulose[b, c]	0.0032	3.4
Cellulose acetate		
Rigid	0.0009	1.0
Plasticized	0.0008	2.4
Rubber hydrochloride		
Type A	0.0010	0.1
Type B	0.0010	0.2
Type C	0.0010	1.3

(a) Permeability = $\dfrac{\text{amount of ethylene oxide (mg.) X film thickness (mils)}}{\text{film area (sq. in.) X time (min.)}}$

(b) Cast from solution.

(c) Plasticized with 10 parts of di (2-ethylhexyl) phthalate per 100 parts of resin.

(d) Indicates that permeability, if any, was below the limits of this method.

* Dick, Marshall and Charles E. Feazel, "Resistance of Plastics to Ethylene Oxide," Modern Plastics, Nov. 1960.

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TABLE V. COMPATIBILITY OF ENGINEERING MATERIALS
WITH ETHYLENE OXIDE MIXTURES*

Materials	Compatible with Liquid Ethylene Oxide	Compatible with 12% Ethylene Oxide 88% Freon 12	Compatible with 10% Ethylene Oxide 90% Carbon Dioxide
METALS, TREATED AND UNTREATED			
Mild steel	Yes (Note 1)	Yes	Yes
Cast iron	Yes (Note 2)	Yes	Yes
Tin	Yes	Yes	Yes
12-Cr steel	Yes (Note 3)	Yes	Yes
17-Cr steel	Yes (Note 3)	Yes	Yes
18-8 stainless steel	Yes (Note 3)	Yes	Yes
316 stainless steel	Yes (Note 3)	Yes	Yes
Durimet 20	Yes (Note 3)	Yes	Yes
Worthite	Yes (Note 3)	Yes	Yes
Si-iron	Yes (Note 2)	Yes	Yes
Copper	(Notes 4 & 5)		
S -bronze	(Notes 4 & 5)		
Al-bronze	(Notes 4 & 5)		
Red brass	(Notes 4 & 5)	Yes	
Yellow brass	(Notes 4 & 5)	Yes	
Si-bronze	(Notes 4 & 5)		
Monel	Yes (Note 2)	Yes	Yes
Nickel	Yes (Note 2)	Yes	Yes
Inconel	Yes (Note 2)	Yes	Yes
Hastelloy B	Yes (Note 1)	Yes	Yes
Hastelloy C	Yes (Note 1)	Yes	Yes
Hastelloy D	Yes (Note 1)	Yes	Yes
Aluminum	Yes (Note 1)	Yes	Yes
Lead	Yes (Note 2)	Yes	Yes
Titanium	Yes (Note 1)	Yes	Yes
Zirconium	Yes (Note 1)	Yes	Yes
Gold	Yes (Note 1)	Yes	Yes
Platinum	Yes (Notes 1 & 6)	Yes	Yes
Tantalum	Yes (Note 1)	Yes	Yes
Silver	(Notes 1 & 7)		
Magnesium alloys	(Notes 1 & 7)		
Nitrite coated steel	Yes		
Phosphate coated steel	No		
Anodized aluminum	No (Note 8)		
Dimetcote No. 3	No (Note 8)		
Sauereisen silicate coating	No (Note 8)		
Mercury alloys	(Note 9)		
PLASTICS AND RESINS			
Polyvinyl chloride	Yes	Yes	Yes
Saran	Yes	Yes	Yes
Teflon	Yes	Yes	Yes
Polystyrene	Yes	Yes (Note 10)	Yes
Polyethylene		Yes	Yes
Polymethyl methacrylate	No	Yes (Note 10)	Yes
Tygon		Yes	Yes
Kel-F	Yes (Note 12)	Yes	Yes
Nylon	Yes	Yes	Yes
Polyvinyl butyral	Yes	Yes	Yes
Cellulose acetate		Yes	Yes
Fluorothane	Yes		
Polybutyl methacrylate	No		
Cellulose	No		
Polyvinyl alcohol	No		
Vinyl, type R-1	Yes		

* Willard, Myra and V. K. Entrekin, "Surveyor Sterilization Part II:
A Literature Review of Physical, Chemical, and Biological Properties
of Ethylene Oxide — Freon 12 and Its Compatibility with Materials and
Components," Hughes Aircraft RS-283, March 1962

TABLE V. COMPATIBILITY OF ENGINEERING MATERIALS WITH ETHYLENE OXIDE MIXTURES* (Continued)

Materials	Compatible with Liquid Ethylene Oxide	Compatible with 12% Ethylene Oxide 88% Freon 12	Compatible with 10% Ethylene Oxide 90% Carbon Dioxide
RUBBERS AND ELASTOMERS			
Neoprene	Yes (Note 13)	Yes	Yes
Hycar		Yes	Yes
Buna N	Yes	Yes	Yes
Natural rubber	(Note 14)		
GRS rubber	Yes		
NON-ELASTOMERIC PACKING			
Pyroid style 650	(Note 15)		
Pyroid 10,000	(Note 16)		
Teflon impregnated asbestos, white	(Note 17)		
Teflon impregnated asbestos, black	(Note 18)		
LUBRICANTS			
Fluorinated hydrocarbons	Yes	Yes	Yes
Silicone grease, thin film	(Note 19)	Yes	Yes
Petroleum based lubricants	No		
MISCELLANEOUS			
Glass	Yes	Yes	Yes
Stoneware	Yes	Yes	Yes
Asbestos	Yes	Yes	Yes
Graphite	Yes	Yes	Yes
Concrete	Yes	Yes	Yes
Garlock #7021 and #734	Yes	Yes	Yes
Teflon impregnated string	(Note 20)		
Calcium silicate insulation	Yes		
Magnesia insulators	No		
Black foamed glass	No		

Note 1. Corrosion rate of < 2 mil/year at 75°F
Note 2. Corrosion rate of < 20 mil/year at 75°F
Note 3. Corrosion rate of < 20 mil/year at 250°F
Note 4. Can catalyze polymerization of ethylene oxide if moisture is present; can cause explosive reaction if acetylene is present.
Note 5. Corrosion rate of >50 mil/year at 75°F
Note 6. Not compatible with hot platinum coil
Note 7. Can catalyze polymerization of ethylene oxide if moisture is present.
Note 8. Polymerizes ethylene oxide
Note 9. Can cause explosive reaction if acetylene is present.
Note 10. Crazed after prolonged exposure
Note 11. Slight attack
Note 12. Swells
Note 13. Attacked by ethylene oxide after prolonged exposure.
Note 14. Some formulations are compatible
Note 15. Questionable compatibility, 9% weight loss
Note 16. Questionable compatibility, 2% weight loss
Note 17. Not compatible, 52% volume gain
Note 18. Questionable compatibility, 19% weight gain
Note 19. Limited compatibility, residue formation after exposure
Note 20. Questionable compatibility, 21% weight gain

TABLE VI. CHEMICALS REACTING WITH ETHYLENE OXIDE*

Acetals
Acetoacetates
Acetonitriles
Acetylenes
Amines
Amides (acid)
Aldehydes
Ammonia
Azides
Acyl halides
Antimony chloride
Acid anhydrides
Alkyl halides
Aluminum chloride
Aniline
Aluminum oxide
Alkoxides
Alcohol
Anhydrous iron chloride
Anhydrous tin chloride
Arsenic chloride
Alkyl hydroperoxides
Aminothiols
Aryldichloroarsines
Aryllithiums
Acetic acid
Bismuth chloride
Bromine
Barium oxide
Bismuth oxide
Carbon disulfide
Cyanates
Cellulose starch
Carbonyl chloride
Cyanoacetates
Chlorine
Cobalt oxide
Chromium oxide and chloride

Cadmium oxide
Carbon
Diboranes
Diethylene glycol
DDT
Dibutylamine
Diethylamine
Ethylene glycol
Ether (Diethyl)
Fatty alcohols
Fatty acids
Guanidine
Grignard reagents
Hydrofluoric acid
Hydrogen sulfide
Hydrogen cyanide
Hydrochloric acid
Halohydrins
Iodine
Iron oxide
Ketones
Lanolin
Lauric acid
Malonates
Mercury fulminate
Magnesium chloride
Manganese chloride
Molybdenum oxide
Metal Alkyls
Mercaptobenzothiazole
Nitric acid
Nitrogen tetraoxide
Nickel oxide
Nitrosyl chloride
Phenyl magnesium bromide
Polyvinyl alcohol
Phenols
Phosgene

Phosphoric acid
Phosphorous acid
Phosphorous oxychloride
Phosphorous trichloride
Phthalimide
Polybasic organic acids
Potassium
Potassium hydroxide
Pyridine
Quinoline
Sodium sulfide
Sodium sulfite
Sulfur dioxide
Sodium thiosulfate
Silicon tetrachloride
Sulfuryl chloride
Silver oxide
Stannous chloride
Stannic chloride
Sulfur
Sodium
Sodium hydroxide
Sodium nitrite
Stearic acid
Thiourea
Thiocyanates
Thiolacids
Thiols
Thionyl chloride
Throium chloride
Tantalum oxide
Titanium oxide
Tannic acid
Triethanolamine
Urea
Zinc chloride
Zinc oxide

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*Willard, Myra, and V. K. Entrekin, "Surveyor Sterilization Part II: A Literature Review of the Physical, Chemical, and Biological Properties of Ethylene Oxide-Freon 12 and Its Compatibility with Materials and Components," HAC RS-283, March 1962.

3.   Conclusions on Degradation Effects

Study of data contained in the technical literature indicates that elec-
tronic components have not been adversely affected by 12% ethylene
oxide and 88% Freon 12 under the test conditions.   This is substantiated
by material compatibility data which shows that the sterilant gas mix-
ture does not react appreciably with most materials.   There is evidence
however, of small degrees of deterioration of epoxies and silicones
which are present in many components.   The fact that many materials
can absorb or be permeable to ethylene oxide indicates the need for
caution in predicting stability of parts after long storage following gas
sterilization.

The requirements of Specification VOL-50503-ETS are more severe
than the exposure conditions to which parts and materials previously
tested have been exposed.   It is expected, therefore, that degradations
previously observed will be aggravated by these more recent exposure
requirements.

Ethylene oxide (ETO) has been shown to be quite residual in silicones,
phenolic laminates, and H film.   Vacuum treatment or heat exposure is
required to remove the absorbed gas readily.

ETO exposure followed by heat has been found to be more severe
than heat followed by ETO when chemical reaction of the material as
well as physical absorption of the gas is possible.   When only physical
sorption is involved, heat exposure after the ETO exposure tends to re-
verse the degradation process by driving out the sorbed gas.

D. TENTATIVE VOYAGER-LANDER PARTS LIST

A tentative Voyager-Lander Parts List (Table VII) has been compiled to permit detailed examination of the specific problems involved in decontaminating the component parts. This list is based upon both the Hi-Rel and Preferred sections of JPL Specification ZPP-2010-SPL-B, "Electronic Part Sterilization Candidates for Spacecraft Applications,"* with numerous deletions and additions, as required, for sterilization compatibility. For reference purposes, the JPL Design Standard (DS) number sare used where assigned and the JPL vendor code is utilized throughout.

This JPL listing was selected for this purpose on the following basis:

1. This list will probably be utilized as a contractual requirement for Voyager-Lander electronics.

2. The component parts included in the list were selected to withstand the heat sterilization requirements of JPL Specification VOL-50503-ETS. Component suppliers are required to certify ability to withstand the heat sterilization requirements for each lot supplied.

3. At least one-fourth of the components have already been qualified to the performance requirements of the applicable JPL Purchase Specification.

4. Another 50% of the part types have completed the 2000 hour life test requirement of the JPL Purchase Specification qualification test program.

5. The list is reasonably complete, representing the majority of part types contemplated for use.

6. The parts contained on the list have been fabricated using most of the processes and materials presently employed in electronic component manufacture. This allows extrapolation of test data with minimum risk and maximum confidence.

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*Hereafter referred to as "SPL"

TABLE VII. TENTATIVE VOYAGER-LANDER COMPONENT PARTS LIST

CAPACITORS						
JPL DS	TYPE	VENDOR	VOLTAGE	CAPACITANCE	STYLE	EIA or VENDOR TYPE
	Ceramic					
804 and 2503	Low Voltage	AVX	100	10 μμf -0.1 μf	Tub., Sub-min	HMC80
2502		VIT	200	10 to 10,000 pf	Rect., Min	VKR
2530		AVX	100	10 pf to 0.01 μf	Tub., Axial	HMC 70
2527	Feed-through	AVX	500 to 1000	10 to 8500 pf	Feed-through, Std	BLF
2528	Stand-off	AVX	500 to 1000	10 to 8500 pf	Stand-off, Std	BLS
	Glass					
802		CGW	300 to 500	0.5 -10,000 μμf	Rect., Std	CYFR, Level B
	Paper					
800		SPR	200 to 600	0.001 -1 μf	Tub., Std	195P
	Tantalum					
805 and 2501	Solid	SPR	6-50	0.0047-330 μf	Tub., Sub-min	350D
2501		KEM	6 to 50	0.0047 to 330 μf	Tub., Sub-min	KG
2507	Wet Foil	GEC	20 to 75	270 to 1800 μf	Rect., Std	15K
2525 and 801		GEC	10 to 100	1.2 to 300 μf	Tub., Std	15K and 16K
	Mylar					
2515		AVX	75 to 300	0.001 to 1 μf	Tub., Std	V423XP
2508		GDL	50 to 600	0.001 to 1 μf	Tub., Std	617G
2508		SPR	50 to 600	0.001 to 1 μf	Tub., Std	127P
	Porcelain					
2511		VIT	300 to 500	0.5 to 1000 pf	Rect. Axial-Radial	CY12, CY16
2514		VIT	300 to 500	0.5 to 1000 pf	Rect. Std	CY13, CY17

TABLE VII. TENTATIVE VOYAGER-LANDER COMPONENT PARTS LIST (Continued)

CONNECTORS				
JPL DS	TYPE	VENDOR	CONFIGURATION	EIA or VENDOR TYPE
311	Circular, Miniature	BDX	Wall Mtg. Receptable	JC00P
313		BDX	Straight Plug	JC06P
315		BDX	Jam Nut Receptacle	JC07P
316		BDX	Through Bulkhead Receptacle	JCB
317		BDX	Cable Connecting Plug	JC01P
318	Protective Cover	BDX	Circular, Miniature (Without Chain)	
319		BDX	Circular, Miniature (With Chain)	
	Hermetic	DEU		22618-12-10P
	High Temperature	PHS		PS
4001	Rectangular, Miniature	CIN	Plug (pins)	DAM-DEM
4002		CIN	Receptacle (sockets)	DAM-DEM

CONTROLLED RECTIFIERS								
JPL DS	VENDOR	P_{RV} and V_{BO} volts	I_R at P_{RV} and I_S at V_{BO}	I_H ma	V_{GT} volts	I_{GT} ma	CASE	EIA or VENDOR TYPE
675 and 5002	SSP	200	1.0 μa max	0.3 to 5.0	0.4 to 0.8	-5 to +200 μa	TO-9	2N1874A
676 and 5003	GEC	400	2.0 ma max	1.0 to 50 max	0.5 to 3.0 max	2.0 to 40 ma max at 25°C	TO-48	C35DR700
5001	SSP	100	20.0 na max	0.5 to 2.0 max	0.44 to 0.6 max	-5 to +20 μa	TO-18	2N3032

CONTROLLED SWITCH								
JPL DS	VENDOR	V_{CE} volts	$-V_{CE}$ volts	I_{CER} na max	I_{EBO} μa max	I_{BR} μsec	CASE	EIA or VENDOR TYPE
5010	SSP	205	200	50	5.0	5	TO-18	Similar to 2N901

CRYSTALS, FREQUENCY CONTROL				
JPL DS	TYPE	VENDOR	CONFIGURATION	TYPE
*	Hermetically Sealed, 38.4 Kc and 19.125 Mc	**		**

* To be assigned.

** Valpex-Fisher Corp., McCoy Electric Corp., Reeves Hoffman, CTS Knights, Monitor Products, Midland Wright Mfg. Co.

TABLE VII. TENTATIVE VOYAGER-LANDER COMPONENT
PARTS LIST (Continued)

DIODES							
JPL DS	TYPE	VENDOR	I_O ma	PIV volts	I_R at PIV μa	CASE	EIA or VENDOR TYPE
3004	Power	WEC, GEC	35 a	200	300.0	1/4 inch Stud	1N1186
3006		GEC	12 a	600	50.0	Stud	1N1206A
3002 and 606	General Purpose	FAS, TRW	200	175	5.0	Glass, Sub-min	1N485B
3003 and 610		TRW	400	600	0.1	Glass, Sub-min	1N649
3001	Signal and Computer	FAS	75	75	0.025 at 20 v	Glass, Sub-min	1N916
607		FAS	300	125	2	Glass, Sub-min	FD306
604		FAS	300	60	100	Glass, Sub-min	FD643

JPL DS	TYPE	VENDOR	VOLTS	WATTS	CASE	EIA or VENDOR TYPE
3001 and 600	Reference General Purpose	TRW, DIK MOT	3.3 through 91	0.4	Glass, Sub-min	1N746A through 1N759A 1N964B through 1N984B
3009		MOT, DIK	6.8 through 62	1.0	Flangeless	1N3016B through 1N3039B
3010		DIK, MOT	6.8 through 27	10	Stud	1N2970B through 1N2988B
3014		DIK	6.8 through 24	50	1/4 inch Stud	1N3305B through 1N3321B

JPL DS	TYPE	VENDOR	V_Z volts	I_Z ma	ΔV_Z mv	CASE	EIA or VENDOR TYPE
3015	Reference Precision	DIK, MOT	5.9 to 6.5	7.5	9	Class, Sub-min	1N827A
3017		DIK, MOT	8.9 to 9.7	10.0	14	Glass, Sub-min	1N2623A

JPL DS	TYPE	VENDOR	I_O ma	V_F mv	I_R at V_R = 150 v	BV at 5.0 μa	EIA or VENDOR TYPE
3027	Quad	FAS	100	±10 matched at 3.0 ma	100 na max	200 v min	FSA 1321

* To be assigned

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TABLE VII. TENTATIVE VOYAGER-LANDER COMPONENT
PARTS LIST (Continued)

FUSES					
DS JPL	VENDOR	VOLTAGE	CURRENT	CASE	EIA or VENDOR TYPE
*	LTF		Various	Axial, Sub-min	(275)
*	BUS		1/4 and 2 AMP	Axial, Sub-min	A

INDUCTORS - RADIO FREQUENCY				
DS JPL	TYPE	VENDOR	INDUCTANCE RANGE	EIA or VENDOR TYPE
*	Molded	DEL		2500 Series
*	Molded	DEL		1840 Series
*	Molded	NYT		RFC Series
*	Molded	ADE		24350 and 24351 Series

INDUCTORS - LOW FREQUENCY				
DS JPL	TYPE	VENDOR	INDUCTANCE RANGE	EIA or VENDOR TYPE
*	Toroidal	TRI		**EC Series
*	Toroidal	UTC		HL Series
*	Toroidal	COC		**Specials
*	Toroidal	HAD		**Specials
*	Laminated	COC and HAD		**Specials
*	Laminated	MCE		**EA Series

*DS number to be assigned to parts after evaluation and approval.
**Specific Class F (155°C) Construction

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TABLE VII. TENTATIVE VOYAGER-LANDER COMPONENT
PARTS LIST (Continued)

MICROCIRCUITS										
DS JPL	TYPE	VENDOR	TOTAL t_d	I_{CBO}		FAN IN	FAN OUT	P_{typ}	CASE	EIA or VENDOR TYPE
6000	Gate NAND-NOR	FAS	35 nsec	100 µa	1 mc	3	4	15 mw	TO-5	µLG 903
6012	Gate NAND-NOR	SGN	30 nsec	500 µa	1 mc	5	5	8.5 mw	Special	SE 101G
6006	Gate OR	TIX	100 nsec	100 µa	1 mc	5	5	11 mw	Special	*SN 515
6005	Gate NAND-NOR	TIX	65 nsec	100 µa	1 mc	6	5	7 mw	Special	*SN 512
6001	Flip-Flop RS	FAS	35 nsec	100 µa	1 mc	2	4	30 mw	TO-5	µLF 902
6004	Flip-Flop RS	TIX	300 nsec	100 µa	1 mc	4	4	7 mw	Special	*SN 510 SN 511
6013	Flip-Flop RS	SGN	20 nsec	500 na	10 mc	4	8	16 mw	Special	SE 124G
6002	Half Shift Register	FAS	70 nsec	100 µa	1 mc	2	4	75 mw	TO-5	µLS 905
6003	Buffer (Element)	FAS	35 nsec	100 µa	1 mc	3	5	25 mw	TO-5	µLB 900
6016	Power	SGN	90 nsec					60 mw	Special	SE 110G
6017	Dual NAND-NOR Exclusive - OR	SGN	60 nsec					17 mw	Special	SE 115G
6018	Diode Array/AND	SGN						100 mw	Special	SE 105G
6021	Dual NAND-NOR	SGN	60 nsec					20 mw	Special	CS 700G
6022	Dual Diode Array/AND	SGN						100 mw	Special	CS 705G
6023	Dual Diode Array/AND	SGN						100 mw	Special	CS 709G
6019	Line Driver	SGN	90 nsec					60 mw	Special	SE 150G
6020	Monostable Multivibrator	SGN	60 nsec					16 mw	Special	SE 160G
•		FAS								µA 709
*		FAS								9000 Series
•		GME								PL Series
*	Operational Amplifier	PHILBRICK	GAIN = 20,000; BW = 50MHz						TO-5	Q 25AH

*To Be Assigned

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TABLE VII. TENTATIVE VOYAGER-LANDER COMPONENT PARTS LIST (Continued)

RELAYS						
DS JPL	TYPE	VENDOR	CONTACT ARRANGEMENT	CONTACT RATING	APPROXIMATE OPERATE POWER	EIA or VENDOR TYPE
966 and 4509	Crystal Can Magnetic Latching	GEC	DPDT Form C	2a at 28 vdc Resistive. 1a at 115 vac Resistive.	75 mw	Series 3SAM
963 and 4501	Crystal Can Non-Latching	FIL	DPDT Form C	1a max Inductive (100 millijoules, 6 msec). 2a at 28 vdc Resistive. Also Dry Circuit.	250 mw	Series BRJ
965 and 4506		GEC	DPDT Form C	3a at 28 vdc Resistive. 2a at 115 vac, Inductive. 1a at 28 vdc Inductive. (25 msec).	300 mw	Series 3SAF
967 and 4505		BAB	DPDT Form C	3a at 32 vdc Resistive. 2a at 115 vac, 400 cps Resistive. 1a at 32 vdc Inductive.	240 mw	Series BR12
971 and 4508	1/2 Crystal Can Magnetic Latching	FIL	DPDT Form C	1a max Inductive (100 millijoules, 6 msec). 2a at 28 vdc Resistive. Also Dry Circuit.	150 mw	Series DJL
973 and 4507		BAB	DPDT Form C	2a at 32 vdc Resistive. 1a at 115 vac, 400 cps Resistive. 1/2a at 32 vdc Inductive.	175 mw	Series BR17
4503	Crystal Can Magnetic Latching	SIG	DPDT Form C	Dry Circuit - 1/2a at 28 vdc and 120 vac Resistive. Wet Circuit - 2a at 28 vdc and 120 vac Resistive.	100 mw	Series 32
4500	Crystal Case Non-Latching	SIG	DPDT Form C	Dry Circuit - 1/2a at 28 vdc and 120 vac Resistive. Wet Circuit - 2a at 28 vdc and 120 vac Resistive	200 mw FW and VW adjustment	Series 33

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	RESISTORS, FIXED						
JPL DS	TYPE	VENDOR	WATTS	TOL percent	STANDARD TC(PPM/°C)	R RANGE ohms	EIA or VENDOR TYPE
5534	W.W., Power, Precision	DAL	1	±1	20, 40, 80	0.5Ω to 1.0K	AGS-1
5535			2	±1	20, 40, 80	0.1Ω to 16.2K	ARS-2
5536			2.25	±1	20, 40, 80	0.1Ω to 2.67K	AGS-3
5537			4	±1	20, 40, 80	0.1Ω to 4.12K	AGS-5
5538			5	±1	20, 40, 80	0.1Ω to 12.0K	ARS-5
5539			7	±1	20, 40, 80	0.1Ω to 12.4K	AGS-10
5540			10	±1	20, 40, 80	1.0Ω to 40.0K	ARS-10
5560	Encapsulated	ULT	0.15	±0.1	*	0.1Ω to 15K	202A
5561		ULT	0.15	±0.1	*	15.2K to 80K	202A
5562		ULT	0.25	±0.1	*	0.1Ω to 15K	205A
5563		ULT	0.25	±0.1	*	15.2K to 140K	205A
5564		ULT	0.35	±0.1	*	0.1Ω to 15K	207A
5565		ULT	0.35	±0.1	*	15.2K to 260K	207A
5566		ULT	0.50	±0.1	*	0.1Ω to 15K	307A
5567		ULT	0.50	±0.1	*	15.2K to 420K	307A
5568		ULT	0.70	±0.1	*	0.1Ω to 15K	310A
5569		ULT	0.70	±0.1	*	15.2K to 650K	310A
5570		ULT	1.0	±0.1	*	0.1Ω to 15K	510A
5571		ULT	1.0	±0.1	*	15.2K to 1.7M	510A
5572		ULT	1.5	±0.1	*	0.1Ω to 15K	515A
5573		ULT	1.5	±0.1	*	15.±K to 3.0M	515A
5574		ULT	2.0	±0.1	*	0.1Ω to 15K	520A
5575		ULT	2.0	±0.1	*	15.2K to 4.0M	520A
5500	Glass Carbon Film	TIX	1/8	±1	0 to -500	10Ω to 100K	CG
5501			1/4	±1	0 to -500	10Ω to 1.5M	CG
5506	Molded Metal Film	IRC	1/2	±1	±25 -100	50Ω to 1.5M	MEC
5507			1	±1	±25 -100	50Ω to 4 M	MEF
5551	Coated Metal Film	IRC	1/10	±1	±100	30.1Ω to 301K	CCM(T-1)
5552			1/10	±1	±50	30.1Ω to 301K	CCM(T-2)
5553			1/10	±1	±25	30.1Ω to 301K	CCM (T-9)
5554		IRC	1/8	±1	±100	30.1Ω to 499K	CCA (T-1)
5555			1/8	±1	±50	30.1Ω to 499K	CCA (T-2)
5556			1/8	±1	±25	30.1Ω to 499K	CCA (T-9)
5557		IRC	1/4	±1	±100	30.1Ω to 1M	CCB (T-1)
5558			1/4	±1	±50	30.1Ω to 1M	CCB (T-2)
5559			1/4	±1	±25	30.1Ω to 1M	CCB (T-9)
5528	Carbon Composition	ABC	1/4	±5	1500	10Ω to 22M	CB
5529			1/2	±5	1500	10Ω to 22M	EB
5530			1	±5	1500	10Ω to 22M	GB
5512		IRC	1/2	±5	1500	10Ω to 22M	GBT
5513			1	±5	1500	10Ω to 22M	GBT
5548	W.W., Power, Precision	DAL	10	±1	30, 50, 100	0.1Ω to 5620	RHM-10
5548		SAG	10	±1	30, 50, 100	0.1Ω to 5620	3010M
5549		DAL	15	±1	30, 50, 100	0.1Ω to 12.1K	RHM-25
5549		SAG	15	±1	30, 50, 100	0.1Ω to 12.1K	3225M
5550		DAL	20	±1	30, 50, 100	0.1Ω to 39.2K	RHM-50
5550		SAG	20	±1	30, 50, 100	0.1Ω to 39.2K	3550M
*	Glass Metal Film	IRC	1/8	±1/2	±25	100Ω to 100K	XLT

*To be assigned

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TABLE VII. TENTATIVE VOYAGER-LANDER COMPONENT PARTS LIST (Continued)

RESISTOR, VARIABLE (Potentiometer)						
JPL DS	TYPE	VENDOR	WATTS	R RANGE ohms	TOL (percent)	EIA or VENDOR TYPE
	Trimming					
5750	Carbon Comp	BOU	1/4	5K-5M	±20	3051
5751	Wirewound	BOU	1/2	100Ω-20K	±5	224-500
5753		BOU	1	100Ω-50K	±5	3280L, P and W
*	Metal Glaze	IRC		100Ω-1M		251

*To be assigned

SWITCHES					
JPL DS	TYPE	VENDOR	CONTACT ARRANGEMENT	CONTACT RATING	EIA or VENDOR TYPE
	Switches				
8001	Precision Snap	MIS	SPDT	3a at 28 vdc inductive	1HM1
	Action			5a at 28 vdc resistive	

THERMISTORS							
JPL DS	TYPE	VENDOR	Tc at 25°C	R at 25°C	$\dfrac{R\ at\ 0°C}{R\ at\ 50°C}$	TOLERANCE	EIA or VENDOR TYPE
*		VEC		5K	-6.0	+25 percent	35A5
*		VEC		5K	-4.0	+20 percent	35A2
*		VEC		2K	-3.9	+20 percent	32A101
*		VEC		5K	-3.9	+20 percent	33A5
*		TIX				+10 percent	TM 1/8

*Specification and DS numbers to be assigned to parts after evaluation and approval.

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TABLE VII. TENTATIVE VOYAGER-LANDER COMPONENT PARTS LIST (Continued)

TRANSISTORS								
JPL DS	TYPE	VENDOR	V_{CBO}	h_{FE}	V_{CE} sat Max	$P_A 25^{\circ}C$ Max	CASE	EIA or VENDOR TYPE
414	Small Signal							
414 7001	NPN Sil	TIX	45	100	1.0 vdc	300 mw	TO-18	2N930
418 7002	PNP Sil	FAS	20	35	0.2 vdc	360 mw	TO-18	2N995
412 7006	PNP Sil	TIX	25	40	0.2 vdc	300 mw	TO-18	2N2412
417 7005	NPN Sil	FAS	40	40	0.25 vdc	360 mw	TO-18	2N2369
	Medium Power							
409 7007	NPN Sil	FAS, TIX	40	30	0.4 vdc	360 mw	TO-18	2N708
410 7008	NPN Sil	FAS, TIX	100	75	1.2 vdc	500 mw	TO-18	2N910
411 7010	NPN Sil	FAS, TIX, MOT	70	50	1.0 vdc	360 mw	TO-18	2N915
416 7011	NPN Sil	FAS, TIX	·75	100	1.5 vdc	500 mw	TO-18	2N956
402 7014	NPN Sil	FAS, TIX	120	40	5.0 vdc	800 mw	TO-5	2N1893
7012	PNP Sil	TIX	50	30	1.5 vdc	600 mw	TO-5	2N1132
*	PNP Sil	MOT TIX	60	200	0.4 vdc	400 mw	TO-18	2N2907A
7016	NPN Sil	MOT	60	100	1.6 vdc	500 mw	TO-18	2N2222
*	NPN Sil	FAS	80	40	1.0 vdc	800 mw	TO-5	2N2297
	Power							
7023	NPN Sil	STC	80	20	1.0 vdc	8.5 w	TO-5	2N2034
7021	NPN Sil	TIX	125	20	1.25 vdc	60 w	Special	2N2150
*	PNP	MOT	80	50	1.0 vdc	150 v	TO-3	2N3792
*	NPN	MOT	65	10	--	23 w	TO-6	2N3632
	Special Devices Chopper							
7025	NPN Sil	MOT	30	50	3.0 mvdc	500 mw	TO-18	2N2331
7026	NPN Sil	TIX	30	30	0.5 mvdc	600 mw	TO-18	2N2432

* To be assigned

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TABLE VII. TENTATIVE VOYAGER-LANDER COMPONENT PARTS LIST (Continued)

JPL DS	TYPE	VENDOR	BV_{DGO}	gm μmho	I_{DGO}	V_P	CASE	EIA OR VENDOR TYPE
	TRANSISTORS (Continued)							
	Special Devices Field Effect							
7034	N Channel	AMO	50	400	0.5 na	10.0 v	TO-5	FE200
7035	P Channel	TIX	20	1000	10 na	10.0 v	TO-5	2N2497
			BV_{DGS}					
7036	P Channel	SIL	30	1008		4.0 v	TO-18	2N2608
●	N Channel	SIL		1400		6 v	TO-18	2N3631
✲	P Channel	SIL		1400			TO-72	2N2844
✲	N Channel	MOT		1800			TO-18	2N3796
✲	P Channel	FCH		300		6 v	TO-18	FI-100
	Dual Field Effect							
●	P Channel		30	400			TO-5	2N3609
			R_{BBO}	n	V_{EB2}	P_A 25°C		
	Special Devices Unijunction							
7037	N	GEC	6800	0.68	60	450 mw	TO-5	MM/2N491/B
			V_{CBO} Max	h_{FE1}/h_{FE2}	$V_{BE1}-V_{BE2}$	P_A 25°C		
	Special Devices Dual							
7031	NPN Sil	TIX	45	0.9	5 mv	600 mw	TO-5	2N2642
7033	NPN Sil	FAS	100	0.9	5 mv	600 mw	TO-5	2N2060
✲	NPN Sil	FAS	60	0.9	3 mv	600 mw	TO-5	2N2979
✲	PNP Sil	TIX		0.9	5 mv	600 mw	TO-5	2N3350

●To be assigned.

JPL DS	TYPE	VENDOR	CLASS	EIA OR VENDOR TYPE
	TRANSFORMERS			
✲	Toroidal Power	COC and HAD		**Specials
✲	Laminated Power	COC and HAD		**Specials
✲		MCE		**EA Series
✲	Audio	UTC		HR Series
✲		TRI		**SP Series
✲		MCI		**UM Series
✲	Pulse	PSE		EF-71 Series

✲DS number to be assigned to parts after evaluation and approval.
**Specify Class F (155°C) Construction.

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TABLE VII. TENTATIVE VOYAGER-LANDER COMPONENT PARTS LIST (Continued)

WIRE							
JPL DS	TYPE	VENDOR	INSULATION	JACKET	Z Ohms	Cap μμf	TYPE
	Miniature Coax	RAK	Polyolefin				22-174
		SWC	Teflon				RG188/U
	Coax	SWC	Teflon/Glass				RG142/U
		AMP	Teflon				RG87/U
		SWC	Teflon/Glass				RG159/U
		SWC	Teflon/Glass				RG62c/U
		TIM	Teflon	Teflon	50	29.5	RG-141A/U
		MID	Teflon	Teflon	50	29	50-3920CW

WIRE					
JPL DS	TYPE	VENDOR	Insulation	VOLTAGE	TYPE
	Hookup, Single Conductor				
9000	Unshielded and Unjacketed	*	Teflon	600 v	E
9001	Shielded and Jacketed	•	Teflon	600 v	E
	Hookup, Twisted Pair				
9002	Unshielded and Unjacketed	*	Teflon	600 v	E
9003	Shielded and Jacketed	*	Teflon	600 v	E
	Hookup, Triad				
9004	Unshielded and Unjacketed	•	Teflon	600 v	E
9005	Shielded and Jacketed	•	Teflon	600 v	E
	Hookup, Quad				
9006	Unshielded and Unjacketed	*	Teflon	600 v	E
9007	Shielded and Jacketed	*	Teflon	600 v	E
	Hookup, Single Conductor				
9010	Unshielded and Unjacketed	*	Teflon	350 v	ET
9011	Shielded and Jacketed	*	Teflon	350 v	ET
	Hookup, Twisted Pair				
9012	Unshielded and Unjacketed	*	Teflon	350 v	ET
9013	Shielded and Jacketed	•	Teflon	350 v	ET
	Hookup, Triad				
9014	Unshielded and Unjacketed	•	Teflon	350 v	ET
9015	Shielded and Jacketed	•	Teflon	350 v	ET
	Hookup, Quad				
9016	Unshielded and Unjacketed	•	Teflon	350 v	ET
9017	Shielded and Jacketed	•	Teflon	350 v	ET

*Approved Vendors in order of preference: 1. GOR
2. THL, TEN
3. AMS, SUR

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E. CONSTITUENT MATERIALS IDENTIFICATION

As a basis for hypothesizing compatibility of component parts on the Tentative Voyager-Lander Component Parts List with ethylene oxide sterilization, an investigation was made of the materials and processes utilized in the manufacture of these parts.

The listing of constituent materials for each part type is shown in Table VIII. On the basis of analysis of this list of materials, it is hypothesized that each of the parts on the Tentative Voyager-Lander Component Parts List is compatible, subject to verification testing. In compiling the list of materials, the following sources were used:

1. Information obtained from component part manufacturers and their representatives.

2. Catalog sheets and other published information.

3. Process Identification Documentation accumulated by TRW Systems for those components on the TRW Systems Preferred Parts List having commonality with SPL components.

4. Published literature describing manufacturing processes and materials.

5. Information obtained from TRW Systems component parts engineer specialists.

In Table VIII, the column delineating hermetic seal is based upon the generally accepted criteria of a glass-to-metal seal and a leak rate of less than 5×10^{-8} cc per second. At the end of the table, solders, fluxes, marking materials, and solvents common to all parts are listed. Because of similarities in materials and construction, controlled rectifiers and controlled switches are grouped together with transistors.

TABLE VIII. CONSTITUENT MATERIALS OF TENTATIVE VOYAGER COMPONENT PARTS LIST

CAPACITORS

DS NO.	VENDOR & TYPE	LEADS	CASE	INTERNAL	HERM. SEAL
804	AVX HMC 80	DUMET NICKEL GOLD	ORGANIC EPOXY MG3- HYSOL	BARIUM – TITANATE, PALLADIUM ELECTRODES, 588° SOLDER (95% LEAD, 5% SOLDER)	NO
802	CGW CYFR	TINNED COPPER CLAD STEEL	GLASS	GLASS DIELECTRIC ALUMINUM FOIL ELECTRODES	YES
800	SPR 195P	TINNED COPPER CLAD STEEL	TINNED BRASS	ANTIMONY-TIN SOLDER, GLASS, STEEL, 60/40 SOLDER, EPOXY INK, KRAFT PAPER, MYLAR, ALUMINUM ELECTRODES	YES
805	SPR 350D	NICKEL, SOLDER- COATED	SOLDER- COATED BRASS	TANTALUM PELLET & LEAD, ANODIZED, MNO₂ CARBON IMPREGNANT, SILVER COATED & 60/40 SOLDER COATED LEADS	YES
801	GEC 15K & 16K	NICKEL, GOLD PLATED & TANTALUM	TITANIUM MYLAR	TITANIUM, GLASS, TANTALUM FOIL, KRAFT PAPER, MLF PAPER (15K), ETHYLENE GLYCOL ELECTROLYTE IN 15K, ELECTROLYTE IN 16K IS PROPRIETARY. TEFLON, ACETATE TAPE BACKED WITH FIBRE	YES
2502	VIT VKR	DUMET- NICKEL/GOLD JACKET	DIALLYL PHTALATE, EPOXY	BARIUM TITANATE, SILVER ELECTRODES, VARNISH, SOLDERED CONNECTIONS	NO
2503	AVX HMC 80	SEE DS NO. 804			NO
2530	AVX HMC 70	SEE DS NO. 804 (EXCEPT DC SILCADE 1400 IMPREGNANT IN CASE AND EPOXY UNDERCOAT IS P504G EPOXYN)			NO
2527	AVX BLF	TINNED COPPER 60/40 SOLDER	BRASS ASTM B-16 SILVER PLATE EPOXY END SEAL	BARIUM TITANATE SILVER/GLASS FRIT ELECTRODES	NO
2528	AVX BLS	SAME AS 2527 ABOVE			
2515	AVX V423XP	GOLD PLATED NICKEL	BRASS, SOLDER COAT TAPE-H FILM	GLASS-METAL SEAL, COLD ROLLED STEEL, 0.00025 MYLAR, ALUMINUM FOIL, NO IMPREGNANT	YES
2508	GDL 617G & 127P	TINNED COPPERWELD	ELECTRO- TINNED BRASS MYLAR SLEEVE	STEEL EYELET, HOT TIN DIPPED. GLASS SEAL, MYLAR DIELECTRIC. 83% TIN, 17% LEAD FOIL ELECTRODE IN 617G. POLYISOL BUTYLENE IMPREGNANT. 60/40 SOLDER, KRAFT PAPER. FISH PAPER. 127P HAS ALUMINUM FOIL ELECTRODE	YES
2511	VIT CY12, 16	DUMET, NICKEL & GOLD	PORCELAIN COATED WITH SILICONE OIL	PORCELAIN DIELECTRIC SILVER ELECTRODES	NO
2514	VIT CY13, 17	SAME AS 2511 ABOVE			NO
2501	SPR 350D	SAME AS 805 ABOVE			YES
2501	KEM KG	NICKEL SOLDER OR GOLD PLATE	SOLDER COATED BRASS-MYLAR SLEEVE	GLASS/METAL SEAL. TANTALUM SLUG AND LEAD. MARKEM EPOXY INK. TANTALUM PENTOXIDE & MNO₂. COLLOIDAL CARBON, SILVER SOLDER. RESIDUAL FLUX	YES
2507	GEC 15K	GOLD PLATED NICKEL LEAD & TANTALUM LEAD	TITANIUM MYLAR	TITANIUM & GLASS HEADER, KRAFT PAPER, MLF PAPER TANTALUM FOIL. 15K ELECTROLYTE ETHYLENE GLYCOL, 16K IS PROPRIETARY. TEFLON. FIBRE BACKED ACETATE. 15K HAS BUTYL CUSHION RING	YES
2525	GEC 15K, 16K	SAME AS 2507 ABOVE			YES

NOTE: HERMETIC SEAL IS DEFINED AS DIRECT METAL-TO-GLASS SEAL HAVING LEAK RATE BETTER THAN 5×10^{-8} CC/SEC

TABLE VIII. CONSTITUENT MATERIALS OF TENTATIVE VOYAGER COMPONENT PARTS LIST (Continued)

CRYSTALS, FREQUENCY CONTROL

DS NO.	VENDOR AND TYPE	LEADS	CASE	INTERNAL	HERM. SEAL
•	** 38.4 KC AND 19.125 MC	DUMET OR KOVAR	Cu-Ni-Zn ALLOY, OR OGGEN FREE COPPER AND KOVAR	GOLD, ALUMINUM, GLASS, NICKEL, SOLDER EITHER NITROGEN BACKFILL OR VACUUM INTERIOR ENVIRONMENT	YES

* TO BE ASSIGNED
**VENDORS: SEE TENT. PARTS LIST

CONNECTORS

DS NOS.	VENDOR & TYPES	PIN & SOCKET	INSERT.	SHELL.	OTHER	HERM. SEAL
311, 313, 315, 316, 317	BDX JC00P, JC06P, JCB, JC01P;	ALUMINUM, SILVER, BRASS, STAINLESS STEEL	SILICONE & SILICONE-BASED BONDING MATERIAL	ALUMINUM WITH IRIDITE FINISH	NYLON POTTING BOOT, SILICONE BASE AND EPOXY POTTING MATERIAL SOLDER	NO
318, 319	- -	--	--	ALUMINUM WITH IRIDITE FINISH	SILICONE GASKET STAINLESS STEEL CHAIN	• NO

FUSES

DS NO.	VENDOR & TYPE	LEADS	CASE	INTERNAL	HERM. SEAL
--	LTF 275	SOLDER COATED COPPER	STEATITE, SILVER PLATED BRASS FERRULES	ELEMENT IS COPPER ALLOY (POTTING REQUIRED, ECCOCOAT C-26)	NO
--	BUS A				

INDUCTORS, R.F.

DS NO.	VENDOR & TYPE	CORES	LEADS/WIRE	ENCAPSULATION	HERM. SEAL
--	DEL 2500	PHENOLIC, FERRITE, OR POWDERED IRON (FREQUENCY DETERMINES)	COPPER "SOLDEREX" COATED	EPOXY	NO
--	DEL 1840				NO
--	NYT RFC				NO
--	ADE 24350 24351				NO

INDUCTORS, LOW FREQUENCY & TRANSFORMERS

DS NO.	VENDOR & TYPE	CORES	LEADS/WIRE	ENCAPSULATION	OTHER	HERM. SEAL
	ALL TYPES TRI UTC COC HAD MCE PSE MCI	SILICON STEEL NICKEL IRON ALLOY FERRITE POWDERED IRON MOLYBDENUM-PERMALLOY POWDER	POLYTHERMALEZE FORMVAR SOLDEREX COPPER	EPOXY, VARNISH, SILICONE RUBBER,	MYLAR, KRAFT PAPER, EPOXY-GLASS, DACRON, NYLON, CALTON. TERMINALS ARE NICKEL ALLOYS, TINNED COPPER, PHOSPHOR-BRONZE, BRASS INSERTS MAY BE STEEL, STAINLESS, BRASS, BERYLLIUM COPPER	NO

TABLE VIII. CONSTITUENT MATERIALS OF TENTATIVE VOYAGER COMPONENT PARTS LIST (Continued)

MICROCIRCUITS

DS NO.	TYPE	VENDOR	CASE	LEADS	INTERNAL	HERM. SEAL
6000 6001 6002	μLG903 μLF902 μLS905	FAS		GOLD PLATED KOVAR	GOLD, ALUMINUM, KOVAR, SILICON, SILICON DIOXIDE	YES
6012 6013 6016 6017 6018 6019 6020 6021 6022 6023	SE101G SE124G SE110G SE115G SE105G SE150G SE160G CS700G CS705G CS709G	SGN	KOVAR-GLASS	GOLD PLATED KOVAR	SAME AS ABOVE	YES
6004 6005 6006	SN510 SN511 SN512 SN515	TIX	GOLD PLATED ASTM F-15 ALLOY GLASS SEAL F-15 IS 53% Fe, 29% Ni, 17% Co.		SAME AS ABOVE	YES
*	μA709 9000 SERIES PL SERIES Q25AH	FAS FAS GME PHIL-BRICK	KOVAR-GLASS	GOLD PLATED KOVAR	SAME AS ABOVE	YES

*TO BE ASSIGNED

RELAYS

DS NO.	VENDOR & TYPE	CASE	TERMINALS	HEADER	CONTACTS	OTHER	HERM. SEAL
966 & 4509	GEC 3 SAM	COPPER-NICKEL MINOR IRIDIUM & MANGANESE	NICKEL-IRON SOLDER	STEEL OR KOVAR	GOLD OVER SILVER, BERYLLIUM COPPER	COPPER, VARNISH, NYLON, TEFLON, MYLAR, GLASS, BRASS, ENAMEL, ALNICO V, LOW CARBON IRON, CHROME STEEL, STAINLESS NITROGEN, HELIUM, 60/40 SOLDER	YES
965 & 4506	GE 3 SAF	SAME AS 966/4509 ABOVE					YES
963 & 4501	FIL BRJ	NICKEL-SILVER OR COPPER-NICKEL	COPPER, NICKEL, TIN, SOLDER	STEEL	SAME AS 966/4509	SAME AS 966/4509	YES
971 & 4508	FIL DJL						
967 & 4505	BAB BR12	NICKEL-SILVER	COPPER-STEEL (CARPENTER 426) SOLDER	STEEL	GOLD OVER SILVER, MAGNESIUM-SILVER	SAME AS 966/4509 EXCEPT NICKEL PLATED FINISH	YES
973 & 4507	BAB BR17						
4503 & 4500	SIG 32 & 33	NICKEL-SILVER	COPPER-NICKEL SOLDER	STEEL	GOLD OVER SILVER	SAME AS 966/4509	YES

RESISTORS, FIXED

DS NO.	VENDOR & TYPE	LEADS	CASE	INTERNAL	HERM. SEAL
5534 thru 5540	DAL AGS & ARS	TINNED COPPER-WELD	TEFLON SLEEVE & HI TEMP. SILICONE COATING	BERYLLIUM OXIDE (AGS) AND ALUMINA (ARS) CORES. STAINLESS STEEL AND ALLOY 46 END CAPS	NO
5560 thru 5575	ULT 202A 205A 207A 307A 310A 510A 515A 520A	SOLDER COATED COPPER	MOLDED ALKYD RESIN ALLIED #417	ALKYD RESIN BOBBIN EVANOHM WIRE (75% Ni, 20% CR, 2.5% AL, 2.5% Cu) FORMVAR WIRE INSULATION SILASTIC RUBBER DC601	NO

TABLE VIII. CONSTITUENT MATERIALS OF TENTATIVE VOYAGER COMPONENT PARTS LIST (Continued)

RESISTORS, FIXED

DS NO.	VENDOR & TYPE	LEADS	CASE	INTERNAL	HERM. SEAL
5500 5501 5502	TIX CG	SOLDER-COATED COPPER	HARD GLASS	CERAMIC CORE, CARBON FILM, SILVER TERMINATION BANDS, KOVAR END CAPS	YES
5506 5507	IRC MEC & MEF	NICKEL	MOLDED DIALLYL PHTHALATE	CERAMIC CORE (ALUMINA OR STEATITE), NICHROME FILM, SILVER TERMINATION BANDS, NICKEL END CAPS	NO
5551 thru 5559	IRC CCM, CCA, & CCB	SAME AS 5506/5507 EXCEPT FOR HIGH TEMPERATURE EPOXY COATING INSTEAD OF MOLDED CASE			NO
5528 5529 5530	ABC CB, EB, & GB	SOLDER-COATED COPPER	SILICA & RESIN MOLDED	MOLDED CARBON AND RESIN ELEMENT	NO
5512 5513	IRC GBT	SOLDER-COATED COPPER	MOLDED PLASTIC	RESIN & CARBON FILM ON GLASS TUBE. CONDUCTIVE ADHESIVE LEAD TERMINATIONS.	NO
5548 5549 5550	DAL RHM-10, 25, 50	TINNED COPPER-WELD	ANODIZED ALUMINUM MOLDED PHENOLIC SEALANT	CERAMIC CORE (ALUMINA OR STEATITE) COPPER-NICKEL OR NICKEL CHROME ELEMENT STAINLESS STEEL END CAPS	NO
	SAG 3010M 3225M 3550M			SAME AS ABOVE EXCEPT MONEL END CAPS	NO
•	IRC XLT				YES

*TO BE ASSIGNED

RESISTORS, VARIABLE

DS NO.	VENDOR & TYPE	LEADS	CASE	INTERNAL	HERM. SEAL
5750	BOU 3051	GOLD PLATED NICKEL	GLASS FILLED DIALLYL PHTHALATE	ALUMINA SUBSTRATE, "RESISTON" CARBON ELEMENT PALINEY 7 WIPER (PLATINUM-PALLADIUM) SILICONE RUBBER O RINGS, STEEL SHAFT RETAINER STAINLESS STEEL SHAFT	NO
5751 5753	BOU 224-501 3280L,P,W	SAME AS 5750 ABOVE		ALUMINA OR COPPER MANDREL EVANOHM RESISTANCE WIRE (FORMVAR) OTHERWISE SAME AS 5750 ABOVE	NO
•	IRC 251	SAME AS 5750 ABOVE		CERAMIC SUBSTRATE, POWDERED GLASS AND PRECIOUS METALS, STAINLESS STEEL ANODIZED ALUMINUM	NO

*TO BE ASSIGNED

SWITCHES

DS NO.	VENDOR & TYPE	TERMINALS	CASE	INTERNAL	HERM. SEAL
8001	MIS 1HM1	NICKEL-IRON, TIN PLATED	CORROSION RESISTANT STEEL	COLD ROLLED STEEL AND GLASS BEAD HEADER WOBBLEFRAM POLYPROPYLENE, TEFLON SILVER CONTACTS, BERYLLIUM COPPER SPRINGS NITROGEN & HELIUM	YES

SEMICONDUCTORS, DIODES & RECTIFIERS

DS NO.	TYPE	VENDOR	LEADS	CASE	Au	Al	Kovar	Si	SiO_2	OTHER	HERM. SEAL
3027	SAME AS 604, NEXT PAGE										
676 5003	C35	GEC	Kovar	NICKEL	X		X	X	X		YES
3006 3004	1N1206 1N1186	GEC	Kovar	NICKEL	X			X	X	95/5 SOLDER	YES
675 5002	2N1874A	SSP	Kovar	NICKEL	X	X	X	X	X	OFHC COPPER, Al_2O_3, Mo-Mn, Ni	YES

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TABLE VIII. CONSTITUENT MATERIALS OF TENTATIVE VOYAGER COMPONENT PARTS LIST (Continued)

SEMICONDUCTORS, DIODES

DS NO.	TYPE	VENDOR	LEADS	CASE	Au	Al	Kovar	Si	SiO₂	OTHER	HERM. SEAL
600	1N746A thru 1N759A	DIK	DUMET	GLASS	X	X		X		95/5 SOLDER PALLADIUM/TUNGSTEN RIBBON	YES
		MOT	DUMET	GLASS	X	X	X	X	X		YES
		TRW	TINNED COPPER	GLASS	X	X	X	X		NICKEL, TUNGSTEN, PHOSPHOR, PALLADIUM CORNING 7052 GLASS, SILICONE POLYMER	YES
	1N964B thru 1N964B	DIK	DUMET	GLASS	X	X		X	X	95/5 SOLDER, PALLADIUM/TUNGSTEN RIBBON	YES
		MOT	DUMET	GLASS	X	X	X	X	X		YES
		TRW	TINNED COPPER	GLASS	X	X	X	X		SAME AS 600 (TRW) ABOVE	YES
604	FD643	FAS	DUMET	GLASS	X	X	X	X	X		YES
607	FD306	FAS	DUMET	GLASS	X	X	X	X	X		YES
606	1N485B	FAS	DUMET	GLASS	X	X	X	X	X		YES
		TRW	TINNED COPPER	GLASS		X		X		SAME AS 600 (TRW) ABOVE	YES
3001	1N916	FAS	DUMET	GLASS	X	X	X	X	X		YES
3002	SAME AS 606 ABOVE										YES
3003 610	1N649	TRW	TINNED COPPER	GLASS	X	X	X	X		SAME AS 600 (TRW) ABOVE	YES
3009 3010 3014 3015 3017 3011	SAME AS 600 ABOVE										YES

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TABLE VIII. CONSTITUENT MATERIALS OF TENTATIVE VOYAGER COMPONENT PARTS LIST (Continued)

SEMICONDUCTORS, TRANSISTORS

DS NO.	TYPE	VENDOR	LEADS	CASE	Au	Al	Kovar	Si	SiO$_2$	OTHER	HERM. SEAL
7016	2N2222	MOT	DUMET								
7037	2N491B	GEC									
7036	2N2608	SIL				X			X		
7034	FE-200	AMO									
7023	2N2034	STC								DC 602, 645, PHOSPHOR-BRONZE, 97/3 SOLDER, 52 ALLOY, 1010 STEEL	
5001	2N3032	SSP				X			X		
5010	2N901	SSP								CAT-A-LAC EPOXY POINT Ni, Ag, GERTV 615	
414 & 7001	2N930	TIX	KOVAR	NI	X	X	X	X	X		YES
418 & 7002	2N995	FAS									
412 & 7006	2N2412	TIX									
417 & 7005	2N2369	FAS									
409 & 7007	2N708	FAS, TIX									
410 & 7008	2N910	FAS, TIX									
411 & 7010	2N915	FAS, TIX									
416 & 7011	2N956	FAS, TIX									
402 & 7012	2N1132	TIX									
7014	2N1893	FAS, TIX									
7023	2N2034	STC									
7021	2N2150	TIX									
7025	2N2331	MOT									
7026	2N2432	TIX									
7035	2N2608	SIL									
7031	2N2642	TIX									
7033	2N2060	FAS									
	2N2907A	MOT TIX	KOVAR OR DUMET	STEEL NICKEL ALLOY							
	2N2297	FAS									
	2N3792	MOT									
	2N3632	MOT									
	2N363	MOT									
	2N3631	SIL									
	2N2844	SIL									
	2N3796	MOT									
	FI-100	FCH									
	2N3609	GME									
	2N2979	FAS									
	2N3350	TIX									

*TO BE ASSIGNED

TABLE VIII. CONSTITUENT MATERIALS OF TENTATIVE VOYAGER COMPONENT PARTS LIST (Continued)

THERMISTORS					
DS NO.	VENDOR & TYPES	LEADS	CASE	INTERNAL	HERM. SEAL
--	VEC 35A5 35A2	PLATINUM-IRIDIUM	GLASS-FRIT COATING	METAL-OXIDE SEMICONDUCTOR BEAD	NO
--	VEC 33A5 32A101	SOLDER-COATED DUMET	GLASS SHELL	SAME AS ABOVE	YES
--	TIX TM 1/8	SOLDER-COATED & COPPER	MOLDED DIALLYL PHTHALATE	SILICON BAR ON ALUMINA SUBSTRATE PLATINUM OVER GOLD DIFFUSED TERMINATIONS RTV SILICONE RUBBER	NO

TRANSFORMERS

SEE INDUCTORS, LOW FREQUENCY

WIRE					
DS NO.	VENDOR & TYPE	CONDUCTOR	INSULATION		HERM. SEAL
9001 thru 9007	*E	SILVER COATED COPPER	TEFLON AND GLASS BRAID	JACKET IS TEFLON SHIELD IS SAME AS CONDUCTOR	NO
9010 thru 9017	*ET	SAME AS ABOVE	THIN WALL TEFLON AND GLASS BRAID	SAME AS ABOVE	NO
--	RAK 22-174	TINNED COPPER	POLYOLEFIN	SHIELD IS TINNED COPPER, JACKET IS POLYOLEFIN	NO
--	SWC RG188/U	SILVER-COPPER STEEL	TEFLON	SILVER-COPPER SHIELD TEFLON JACKET	NO
--	SWC RG142/U	•	TEFLON	SAME AS ABOVE PLUS SILICONE VARNISHED GLASS BRAID OVERALL	NO
--	AMP RG87/U	SILVER-COPPER	TEFLON	• •	NO
--	SWC 159/U	•	TEFLON	• •	NO
--	SWC RG62C/U	SILVER-COPPER AND STEEL	TEFLON	• •	NO
--	TIM RG141A/U	•	TEFLON	• •	NO
--	M'D 50-3920 CW	COPPER-STEEL	TEFLON	SHIELD IS SILVER AND COPPER JACKET IS TEFLON	NO

*VENDORS: GOR, THL, TEN, AMS, SUR

SOLAR CELLS*					
DS NO.	VENDOR & TYPE	CONTACTS (BOTH)	TOP SURFACE	OTHER	HERM. SEAL
--	HOF RCA	SOLDER ON ELECTROLESS NICKEL EVAP. TITANIUM	SILICON MONOXIDE	SILICON, UV FILTER (PROPRIETARY), QUARTZ OR BOROSILICATE GLASS BONDED ON WITH DC-XR6-3489 SILICONE ADHESIVE. REAR SURFACE SAME AS CONTACT. GLASS OR QUARTZ HAS ANTI-REFLECTANT, USUALLY MAGNESIUM FLUORIDE	NO

*SOLAR CELLS NOT ON JPL STERILIZATION PARTS LIST - FOR INFORMATION ONLY

TABLE VIII. CONSTITUENT MATERIALS OF TENTATIVE VOYAGER COMPONENT PARTS LIST (Continued)

COMMON SOLVENTS

TYPE	RESIDUES
TRICHLORETHANE ALCOHOL DEIONIZED WATER ACETONE	NONE

COMMON SOLDERS

TYPE		RESIDUES
SN60 SN63 SN62 PURE TIN	60% TIN, 40% LEAD 63% TIN, 40% LEAD 62% TIN, 3% Pb, 2% Ag HAS 1% Sb	TIN AND LEAD OXIDES

COMMON FLUXES

TYPE		RESIDUES
WATER SOLUBLE		ZINC OXY CHLORIDE
ROSIN		NONE

MARKING MATERIALS

TYPE	
INDEPENDENT 73X LACQUER MARKEM 7906 EPOXY MARKEM 7123 EPOXY WORNOW MXM EPOXY WORNOW CAT-L-INK EPOXY SPRINT FILM BRADY B-600 (MYLAR + ADHESIVE) WESTLINE WIRE MARKERS ECCOCOAT EC200	

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F. COMPATIBILITY FINDINGS

The information compiled during the compatibility study has resulted in development of the Tentative Voyager-Lander Component Parts List (Table VII) containing those part types which can reasonably be assumed to be compatible with ethylene oxide sterilization procedures.

Judgments are based on previous test data on a particular or similar part, projection of possible added deterioration due to the more severe environmental conditions now specified, possible reactions of ethylene oxide or Freon 12 with the case materials, hermeticity of the part, and possible reactions of ethylene oxide and Freon 12 with internal materials of non-hermetically sealed parts. Where breaking the hermetic seal would not destroy a part, possible reactions of the sterilant gas with the internal materials of these parts have been considered.

Approximately 20% of the listed parts had been tested previously and were found to be essentially unaffected by the exposure. These are judged to be probably compatible with present exposure requirements, but should be tested because of possible degradation mechanisms. For example, intake of ethylene oxide by the silicone coating on DS2511 and 2514 capacitors, and DC 5534 through 5540 resistor cases may reduce the insulation resistance of the cases. The gas may also leak into the interior of DC 5534 through 5540 resistors, which are not hermetically sealed, and may react, depositing a polymer film on the metal oxide cores, when these parts become heated during operation. DS 5560 through 5575 resistors and one DS 600 diode contain silicone polymers, which can absorb ethylene oxide. All epoxy-containing parts are potentially degradable by the gas.

Similar degradation mechanisms are possible in many of the remaining parts which have not been tested previously.

The only part type which is judged to be compatible without further testing is the DC 802 glass capacitor. This capacitor contains no reactive materials and is made in such a monolithic manner that a great deal of confidence can be placed in its freedom from deleterious effects.

Hermetically sealed parts having a glass-to-metal seal should also be compatible since currently available sealing technology and testing methods are very effective. However, in instances where the possibility of seal breakage, as a result of testing, handling, or assembly exists, and where interior materials of these parts are potentially reactive, it seems prudent to question compatibility and recommend further testing.

Besides reacting directly with a part, the sterilant gas may react with flux residues or markings. Possible flux residues and marking materials are shown in Table VIII. It is not expected that products of these reactions would be corrosive, but the possibility should not be overlooked. A program to test many of these marking materials is currently being conducted by TRW Systems. Results of this program should be examined before further tests are planned.

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June 6, 1966   Report No. 5538-6002-R0000

STUDY OF ETHYLENE OXIDE EFFECTS

ON COMPONENTS

PART II. RECOMMENDED TEST PROGRAM

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Contract No. 951439

California Institute of Technology
Jet Propulsion Laboratory
Pasadena, California

Subcontract under NASA Contract NAS7-100
Task Order RD-4

TRW SYSTEMS
ONE SPACE PARK · REDONDO BEACH, CALIFORNIA

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PART II. RECOMMENDED TEST PROGRAM

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PART II. RECOMMENDED TEST PROGRAM

A. SUMMARY OF RECOMMENDED TEST PROGRAM

The test program recommended by TRW Systems as Phase III of the Sterilization Test Program Investigation of Ethylene Oxide Effects on Component Parts has been developed as a result of information compiled in the Phase II Study. The test program consists basically of four principal tasks:

1. Test Preparation
2. Pilot Testing
3. Long-Term Testing
4. Statistical Analysis of Test Findings

Objective of the test program will be to prove the ability of the selected list of electronic component parts to withstand the effects of ethylene oxide sterilization procedures and subsequently to perform satisfactorily in planetary spacecraft equipment.

For testing, a selected number of part types has been chosen from the JPL List of Electronic Part Sterilization Candidates for Spacecraft Applications to represent the complete list of all types. For the long-term tests, a quantity of 225 parts of each of 35 part types is recommended. For the pilot tests, a quantity of 120 each of 11 of these part types is recommended. For the entire program, a total quantity of 9195 component parts is thus required.

Preliminary to performance of pilot and long-term testing, careful test preparation is required. This will consist of component examination, screen testing, preliminary burn-in and stabilization, equipment set-up and calibration, and check-out of test procedures.

Purpose of the pilot testing is to determine experimental patterns necessary for design of long-term tests of statistical significance. To accomplish this result, pilot testing will be performed on small samples in a test matrix involving specimens under two different voltage loads, two different temperature levels, ethylene oxide sterilization at three different pressure levels, sterilization without ethylene oxide, and no sterilization. The information obtained from

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pilot matrix testing will be plotted and used as a basis for engineering judgments required for design of the long-term tests.

The long-term tests represent simulation of the entire Voyager-Lander mission, including nine months of space travel and 12 weeks of duty on the surface of Mars. Each sample of 225 parts will be divided into three treatment groups, each consisting of 75 parts. One group will consist of parts subjected to sterilization without ethylene oxide, the second to specification ethylene oxide sterilization, and the third to ethylene oxide sterilization at an increased pressure level. In simulating the Lander duty cycle on Mars, each of the treatment groups of 75 parts will be divided into two subgroups, one operated at normal derated design stress level and the other operated at maximum rated stresses. Measurements will be made of the most sensitive parameters of each of the part types by treatment groups at four critical points in the mission simulation time scale.

Following completion of testing, the data obtained from the tests will be fed to an electronic computer for statistical analysis. The final computer output will show all treatment group comparisons. If no significance is found by the computer on any of the comparisons, the hypothesis that the component parts are unaffected by ethylene oxide sterilization will be definitely proved. If, however, the comparisons indicate statistically significant differences between a treatment group subjected to ethylene oxide according to specification and the group subjected to sterilization without ethylene oxide, then further investigation and degradation analysis of the particular part type will be in order.

The recommended test program which follows indicates the specific component part types recommended for testing, including values and test conditions, precedures for performing tests, the necessary test equipment required, the statistical analysis requirements, and the method of performing the statistical analysis.

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B. TEST PROGRAM

1. Work Statement

To verify the compatibility of component parts included on the Tentative Voyager-Lander Parts List with ethylene oxide sterilization procedures in accordance with JPL Specification VOL-50503-ETS, performance of the following test program by TRW Systems is recommended. The test program will be performed on a total sample of 9195 specimens of 35 part types, including 225 each of 24 types and 345 each of 11 types which will be used both for pilot and long-term testing. It is anticipated that all parts will be procured by JPL to controlled purchase specifications for the test program, together with a suitable number of spare parts, probably not to exceed 5%. Test program tasks (Figure 1) will be as follows:

Task 1. Test Preparation. Upon receipt of component parts, all devices will be subjected to visual examination and electrical testing to manufacturer specifications. Preliminary burn-in and screening measurements of sensitive parameters will be performed in order to assure validity of subsequent test results by stabilizing parts and minimizing drift. Test procedures will be prepared and checked out and test equipment will be calibrated and set up. Procedures and records will be submitted to JPL following completion of test preparation.

Task 2. Pilot Testing. Pilot testing will be performed on quantities of 120 each of eleven part types, as scheduled, in order to verify experimental procedures and permit selection of statistical test methods based on actual test results. Pilot tests will be performed on small samples in a test matrix involving rated and derated electrical loads, maximum rated and anticipated mission operating temperatures, with specimens not subjected to sterilization, sterilized without ethylene oxide, sterilized with ethylene oxide at 5 psi (VOL-50503-ETS pressure), 12 psi, and 18 psi. Testing will be performed for a three-week period. Test results will be plotted to determine conditions and measurements required for long-term testing. Test results and plots resulting from pilot testing will be submitted to JPL.

Task 3. Long-Term Testing. Long-term tests will be conducted on quantities of 225 specimens of each of 35 part types under conditions simulating the Voyager-Lander mission. Tests will consist of nine months

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of non-operating storage followed by 12 weeks of temperature and electrical operation loading. Specimens will be divided into three equal groups of parts, sterilized in accordance with Specification VOL-50503-ETS with ethylene oxide at the specification 5 psi pressure, without ethylene oxide, and with ethylene oxide at a higher pressure to be determined as a result of the pilot testing. Measurements of sensitive electrical parameters will be made at 4.5 and 9 months of storage and at 6 and 12 weeks of operation.

Task 4. <u>Statistical Analysis of Test Findings</u>. Test measurement data obtained during long-term tests will be fed to an electronic computer through magnetic tape or punch cards, depending upon the part type, for statistical comparison and analysis. The computer program will determine whether the three sterilization treatment groups of each part type in the long-term tests differ significantly in performance. All component parts which show no significant differences in sensitive parameters will be determined to be immune to degradation by exposure to ethylene oxide sterilization procedures. If any part types show significant differences among sterilization treatment groups, further investigation and degradation analysis will be recommended. Data will be summarized in a final report.

2.   <u>Plan of Accomplishment</u>

The program as outlined in the work statement and Figure 1 can be accomplished in a period of 20 months. This time schedule is based upon an estimated one-month period following receipt of parts for test preparation (Task 1), two months for pilot testing (Task 2), fourteen months for long-term mission simulation tests (Task 3), and three months for statistical analysis and preparation of the final report (Task 4) including the time required for final report draft submission and approval.

In addition to the final report, which will completely document all test procedures and test results as well as determinations of the immunity of each part type to ethylene oxide sterilization, a comprehensive plan of reporting is contemplated. Monthly reports will be submitted each month during the life of the program outlining all work accomplished during the reporting period and plans for the next period. At the time of submission of each monthly report, test data accumulated during the reporting period

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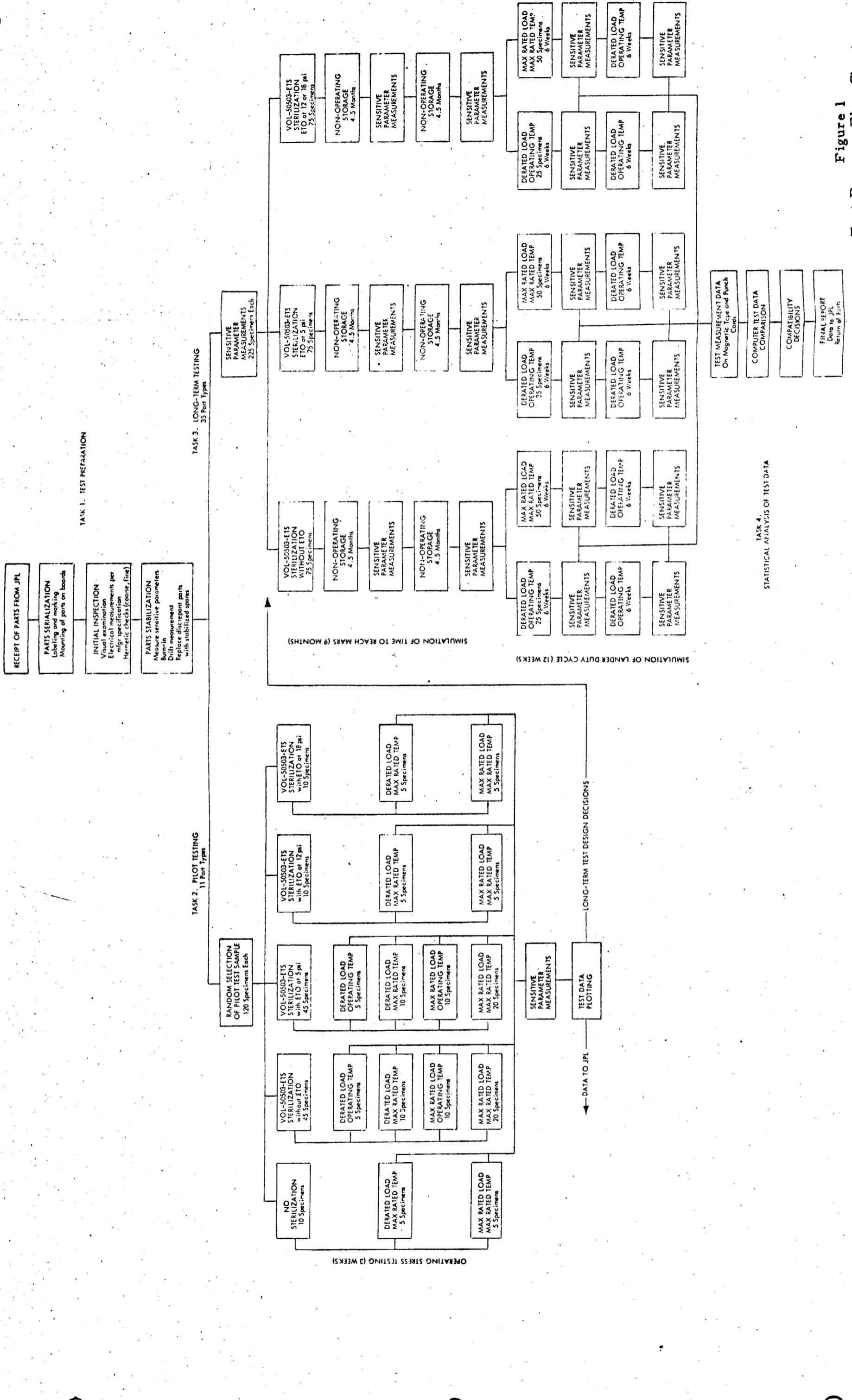
Figure 1
Test Program Flow Chart

will be forwarded for review. Following the completion of Task 1, test
procedures, component part test and burn-in measurement data, and test
equipment calibration records will be submitted. Following completion
of Task 2, test results and statistical plots resulting from pilot testing
will be submitted. At the conclusion of the program, all component parts
will be returned to JPL.

During the entire program, close liaison will be maintained with
the JPL cognizant engineer for interchange of information and program
requirements. JPL representatives will be invited to witness significant
tests and to review measurement and analysis data. Comments by JPL
representatives will be solicited continuously during the program. Free
access to program and test facilities will be furnished to JPL representa-
tives on a non-escort basis. All data will be available for viewing upon
request at all times.

In addition to the number of test samples required for the conduct
of this program, it should be noted that small quantities of spare parts will
be required. These spares will be used to replace parts found defective
upon receipt or following burn-in. Since the part types will be procured
to controlled specifications and subjected to careful handling, it is not
contemplated that a large number of spares will be required, probably not
to exceed 5%. Parts destroyed by application of stresses during the pilot
test will not normally be replaced because of the nature of the testing. If
failures occur during long-term testing, failed parts will not be replaced
since these failures would represent significant test information.

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C. RECOMMENDED TEST PROCEDURES

1. Components Selected for Testing

Components selected for both pilot testing and long-term testing have been chosen to provide a maximum amount of information on all parts on the Tentative Voyager-Lander Parts List. Decisions regarding selection of test types have been engineering-founded, based upon the constituent materials list and previous testing experience with the same or similar types of devices.

The listing of parts to be tested in this program (Table I) includes 11 types to be used for the pilot test and 35 types to be used for the long-term tests. All of these components appear on the JPL List of Electronic Part Sterilization Candidates for Spacecraft Applications (Specification ZPP-2010-SPL-B).

Test results on the parts included in the test list (Table I) will result in valid qualification judgments on a considerably larger list of additional parts on the basis of qualification by similarity. Similar components in the Voyager-Lander parts list for which these judgments can be made are indicated for each part type in Table I.

The long-term test samples for fuses and frequency-determining crystals consist of component parts fabricated by two different manufacturers and the sample of RF inductors respresents four different manufacturers. In these three instances, these will be treated as three individual part types since construction is essentially the same. Information on performance of the sub-types will prove advantageous.

Parts selected for the pilot test are those adjudged most prone to show degradation on the basis of the findings of the study phase of this program. Most of the pilot test parts are not hermetically sealed and contain constituent materials that may cause problems when exposed to ethylene oxide.

Only one component type, the glass capacitor, has been omitted entirely from the list of components to be tested. This has been done because the monolithic structure of this component is composed completely

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TABLE I. COMPONENT PARTS RECOMMENDED FOR TESTING

Part Type	Vendor and Type No.	Value Selected for Test	Pilot Test Quantity	Long Term Test Quantity	Similar Components in Voyager-Lander Parts List — Vendor and Type No.	Previously Tested*	Most Sensitive Indicators	Secondary Indicators	Stabilization Method	Degradation Mechanism	Test Equipment and Accuracy	Hermetic Sealing for Test
CAPACITORS Ceramic	AVX HMC30 AVX BLF-1	0.1 uf, 100v 8500 pf, 500v	-- 120	225 225	(AVX HMC80) VIT VKR (AVX BLF-1) AVX BLS AVX HMC70	Yes Yes No No No	Insulation resistance Dielectric breakdown after moisture	Capacitance Power factor	250 hour burn-in at max rated temperature and twice max rated high temperature voltage	Absorption of sterilant by plastic case aggravated by moisture	Megohmeter ±2% Capacitance bridge ±0.01% Dielectric tester ±5%	Not sealed
Paper	SPR 195P	1.0 uf, 600v	--	225	(SPR 195P)	No	Insulation resistance (terminal to terminal and terminal to case)	Capacitance Dissipation factor	100 hour burn-in at max rated temperature and twice rated voltage	Bridging of seals and insulation		Seals to be voided for 5 units of each type, except for impreg. type
Mylar	GDL 617G	1.0 uf, 600v	--	225	(GDL 617G) SPR 127P AVX V423XP	No Yes No						
Porcelain	VIT CY16	1000 pf, 500v	120	225	VIT CY12, (CY16) VIT CY13, CY17	Yes No	Insulation resistance	Capacitance Dissipation factor	100 hour burn-in at max rated voltage	Absorption of sterilant by case		Not sealed
Tantalum	GEC 16K SPR 350D	100µf, 50v 15µf, 50v	-- --	225 225	GEC 15K, (16K) (SPR 350D)	No Yes	DC leakage current	Capacitance Power factor	100 hour burn-in at max rated voltage and temp	Bridging of seal	Leakage current fixture ±0.5%	Seals not to be voided
CRYSTALS Frequency Control	Monitor McCoy	38.4kc 19.125mc	-- --	112 112		No No	Frequency Resonant resistance	--	250 hour aging test at max rated temperature	Bridging of seal	Crystal test set 0.0001%	Seal not to be voided
FUSE	LTF (275) BUS A	1/4 amp 1/4 amp	-- --	113 113		No No	Resistance	DC resistance Insulation resistance	100 hour burn-in at 70% rated current	Reaction of fuse link with sterilant; absorption by case	Regulated power supply and DC meter ±0.5%	Not sealed
DIODES	GEC 1N1186 TRW 1N649 MOT 1N759A	200v, 35a 600v, 0.4a 12v, 0.4a	-- 120 --	225 225 225	DIK, {1N746A to 1N759A} MOT, {1N964B to 1N984B} TRW; TRW 1N649; WEC, GEC 1N1186; GEC 1N1206A; DIK, {1N2970B to 1N2988B} MOT {1N3016B to 1N3039B} 1N827A, 1N2623A FAS {FD306, FD643, FSA132I, 1N916} DIK {1N3305B to 1N3321}	{Yes} No No No No	Leakage current at 80% rated voltage and 125°C	Forward voltage per spec rating	48 hour bake at 150°C	Surface degradation due to seal bridging	Fairchild 4000-M tester ±0.1%	Seal not to be voided
MAGNETICS RF Inductors	Delevan 2500-42 Delevan 1840-10 NYT RFC-S-10 NYT RFC-S-100	2000µh 1.0µh 10µh 100µh	120 -- -- --	57 57 57 57		No No No No	Insulation resistance	Inductance Q	5 temp cycles from -55°C to +85°C	Absorption by case	Megohmeter ±2% Inductance Bridge ±1%	Not sealed
Low Frequency Inductors	UTC HL Series UTC EA Series	1.0 h 1.0 h	-- --	225 225		No No	Insulation resistance	Inductance Q	5 temp cycles from -55°C to +85°C	Absorption by insulation and case	Megohmeter ±2% Inductance Bridge ±1%	Not sealed

TABLE I. COMPONENT PARTS RECOMMENDED FOR TESTING (Continued)

Part Type	Vendor and Type No.	Value Selected for Test	Pilot Test Quantity	Long Term Test Quantity	Similar Components in Voyager-Lander Parts List — Vendor and Type No.	Previously Tested*	Most Sensitive Indicators	Secondary Indicators	Stabilization Method	Degradation Mechanism	Test Equipment and Accuracy	Hermetic Sealing for Test
MICROCIRCUITS	SGN SE101G	Gate NAND-NOR	--	225	All types	No	Leakage currents of output buffer and input diodes at 125°C	"1" and "0" output voltages and "1" input currents at 125°C	48 hour bake at 175°C	Surface damage to junction areas if seal is broken	Fairchild 400-M tester ±0.1%	Seals to be voided for 5 units of each type
RELAYS	GEC 3SAM FIL DJL	75mw 150mw	-- --	225 225	FIL {Series BRJ, Series DJL} GEC {Series 3SAM, Series 3SAF} BAB {Series BR12, Series BR17} SIG {Series 32, Series 33}	No	Contact resistance (dry circuit)	Pull-in voltage Drop out voltage Insulation resistance	Operation for 1000 cycles	Bridging of header and reaction with contact materials	Power supply and meters ±0.5%	Seals to be voided for 5 units of each type
RESISTORS Carbon composition	ABC CB ABC GB	22m,1/4w, 5% 22m,1w, 5%	120 --	225 225	(ABC CB) ABC EB (ABC GB)	Yes Yes Yes	DC resistance	--	Temperature cycling per MIL-R-11	Absorption of ETO and moisture	Resistance bridge ±0.01%	Not sealed
Molded metal film	IRC MEC	1.5m, 1/2w	120	225	(IRC MEC) IRC MEF	Yes Yes						Not sealed
Coated metal film	IRC CCB(T-9)	1.0m, 1/4w	--	225	IRC {CCM(T-1), CCM(T-2), CCM(T-9), CCA(T-1), CCA(T-2), CCA(T-9), CCB(T-1), CCB(T-2), (CCB(T-9))}	Yes	DC resistance Insulation resistance	Resistance temperature characteristic	100 hour burn-in at 125°C and full rated power	Absorption by case and reaction with resistance film	Resistance bridge ±0.01%	Not sealed
Encapsulated	ULT 520A	4.0m, 2w, ±20ppm/°C	120	225	ULT {205A, 202A, 207A, 307A, 510A, 515A, (520A)}	Yes No	DC resistance Insulation resistance	Resistance temperature characteristic	100 hour burn-in at 125°C and full rated power	Absorption by encapsulant	Resistance bridge ±0.01%	Not sealed
Variable	BOU 3051 BOU 3280L IRC 251	5M 50K 1M	120 -- --	225 225 225	(BOU 3051) (BOU 3280L) (IRC 251)	Yes No No	Insulation resistance Adjusting torque	DC resistance	100 hour temp cycling from 125°C to room temperature	Reaction with case and element; swelling of O-ring	Insulation resistance tester ±5%	Not sealed
Wirewound	DAL ARS-10	40k, 10w, ±20ppm/°C	120	225	(DAL ARS-10)	Yes	Insulation resistance	DC resistance	100 hour burn-in at full rated wattage and max temperature	Absorption by case	Resistance bridge ±0.01% Insulation resistance tester ±5%	Not sealed

TABLE I. COMPONENT PARTS RECOMMENDED FOR TESTING (Continued)

Part Type	Vendor and Type No.	Value Selected for Test	Pilot Test Quantity	Long Term Test Quantity	Similar Components in Voyager-Lander Parts List		Most Sensitive Indicators	Secondary Indicators	Stabilization Method	Degradation Mechanism	Test Equipment and Accuracy	Hermetic Sealing for Test
					Vendor and Type No.	Previously Tested*						
THERMISTOR	VEC 35A5	5K	120	225	(VEC 35A5	No	Resistance at 25°C	--	100 hour burn-in at 125°C	Absorption by resistance element and case	Fairchild 4000M tester ±0.1%	Not sealed
	TIX TM1/8	500 ohms	--	225	(TIX TM1/8)	No	Resistance temperature characteristic					
TRANSISTORS												
Controlled Rectifier	GEC C35DR700	400 volts	--	225			β and I_{CBO}	--	48 hour bake at 175°C	Junction degradation and surface effects	Fairchild 4000M tester ±0.1%	Seals to be voided for 5 units of each type
Controlled Switch	SSP 2N901	200 volts	--	225	All types (See Voyager Lander Tentative Parts List)	No	Drain leakage current					
Medium Power	TIX 2N1132	600mw	120	225			Source leakage current					
Field Effect	SIL 2N2608	30 volts	--	225			D.C. transconductance					
Unijunction	GEC MM/2N491/B	450mw	--	225								
Dual	TIX 2N3350	600mw	--	225								

ALPHA VENDOR SOURCES

ABC	Allen Bradley		MCE	Magnetic Circuit Elements, Inc.
AVX	Aerovox Corp.		MOT	Motorola
BAB	Babcock Engineering Co.		NYT	Nytronics
BOU	Bourns, Inc.		SGN	Signetics Corp.
BUS	Bussman Mfg.		SIL	Siliconix, Inc.
DAL	Dale Products		SPR	Sprague Products Co.
DIK	Dickson Electronics Corp.		SSP	Solid State Products, Inc.
FAS	Fairchild Semiconductor		TIX	Texas Instruments
FIL	Filtors, Inc.		TRW	TRW Semiconductors, Inc. (PSI)
GDL	Goodall Electronic Mfg. Co.		UTC	United Transformer Co.
GEC	General Electric Co.		VEC	Victory Engineering Corp.
IRC	International Resistance Co.		VIT	Vitramon
LTF	Littlefuse, Inc.		WEC	Westinghouse Electric Corp.

* Indicates reference to previous ETO compatibility testing found in Phase II, study and literature search.

of non-reactive constituent materials so that it can be classed as immune from degradation effects without testing.

For each of the part types to be tested, analysis has been made of the most sensitive electrical characteristics most likely to indicate degradation effects, secondary indicators of degradation, the stabilization method recommended for each test type, the degradation mechanism most liable to occur, and the recommended treatment of the hermetic seal. This information is tabulated in Table I together with a listing of the recommended test equipment for measurement of sensitive parameters and the accuracy required.

2. Hermetic Seals

Because of the possibility of breakage of hermetic seals in testing, handling, and assembly of Voyager equipment, an investigation into the consequences of this occurrence appears in order. The compatibility hypothesis of this study assumes that all constituent materials of a component are contacted by the sterilant. This assumption is much easier in the study, however, than in the test phase. The exact procedure for voiding the seal in a transistor, for example, must only avoid contamination of the interior by unusual residue, whereas the voiding of the seal of a glass diode must avoid destruction of the part. Some part types (capacitors) are likely to be damaged by the moisture of the exposure environment, thus invalidating the possibility of sound judgment of degradation effects.

As a result, the procedure of voiding hermetic seals in these tests will require a cautious approach. Hermetically sealed parts for which seal breaking is recommended are indicated in Table I, but it is suggested that only a limited quantity of these components be treated in this manner.

During the initial inspection to be performed as part of the test preparation (Task 1), both coarse and fine hermetic seal testing will be performed. This testing, using helium, will provide positive indication of the effectiveness of the sealing. Since the ethylene oxide molecule is considerably larger than the helium molecule, it can be presumed that if seals are shown to be effective, the leak rate for ethylene oxide will be much smaller. On the basis of this information, some revision of decisions on voiding of hermetic seals may be in order at that time.

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3. Use of Test Boards

As part of the test preparation (Task 1), it is recommended that all parts be mounted on test boards to facilitate handling, prevent the possibility of accidental damage, and to assure positive identification and marking of each specimen. For some part types, standard test boards are available. For others, boards will be fabricated, either by use of printed circuit patterns or by installation of terminals in epoxy-glass laminate boards of suitable size. The advantages of the use of test boards throughout the test program will more than justify the time and effort required initially to fabricate the boards and mount the parts.

4. Test Equipment

For measurement of the sensitive electrical parameters of each part type at the accuracies listed in Table I, the use of a number of items of precision test equipment is required. These special test instruments are listed in Table II together with additional items of laboratory test equipment available for use in the test program listed in Table III.

As part of the test preparation (Task 1), test equipment set-ups will be specified for each part type to be tested. Each test instrument will be specified by serial number as well as by manufacturer type. Prior to use of any instrument in the test program, calibration of the test equipment will be checked. Subsequent to initial usage in this program, there will be no further readjustment of test instruments, thus assuring uniformity of readings. Accuracy checks, however, will be made at intervals and prior to all critical readings.

In order to provide test data for statistical analysis in a form usable by an electronic computer, it will be necessary to have all readings on either punch cards or magnetic tape. For some part types, it will be possible to obtain this type of data directly by use of semi-automatic scanning and measurement instruments. For other data, conversion of test readings to punch card format will be required. The form in which measurements will be recorded will be established as part of the Task 1 test preparation.

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TABLE II. PRECISION ELECTRICAL TEST INSTRUMENTS AND ACCURACIES RECOMMENDED FOR TEST PROGRAM

Description	Manufacturer	Type or Model No.	Nominal Accuracy
Precision Capacitance Bridge, 1 Mc	Booton	75A-S8	±0.5%
RX Meter	Booton	250-A	±0.5%
Pulse Generator, Nanosecond	Hewlett Packard	215A	±5%
Bridge, Admittance	Wayne Kerr	B801	±3%
VHF Bridge Source	Wayne Kerr	S161B	±3%
VHF Bridge Detector	Wayne Kerr	R161	±3%
Transfer-Function and Immittance Bridge, 25 to 1500 Mc	General Radio	1607A	±3%
Complex Ratio Bridge	Gertsch	CRB-8	±0.05%
Digital Readout Oscilloscope	Tektronix	567	±2%
High Frequency Oscilloscope, DC to 95 Mc	Tektronix	585	±3%
High Frequency Electronic Counter, 0 to 1200 Mc	Hewlett Packard	5245L	±1 count
UHF Signal Generator, 450 to 1230 Mc	Hewlett Packard	612A	±1 db
VHF Signal Generator, 10 to 480 Mc	Hewlett Packard	608D	±1%
Panoramic Panalyzor	Singer	SB-12b	±3%
Automatic Integrated Circuit Tester	Fairchild	4000M	±0.1%
Beta Tester, DC, Pulsed	CDC	9503-1	±1%
Saturation Tester, DC, Pulsed	CDC	9509B	±1%
Reverse Voltage Tester, Transistor	CDC	MTD-01-1	±1%
Reverse Current Tester, Transistor	CDC	MTD-02-1	±1%
Transistor Curve-Tracer	Tektronix	575	±3%
Pulsed Sustaining Voltage Tester, Transistor	Eagle Picher	3307	±3%
Semi-Automated Scanning and Measurement System	TRW	RF-1	±0.1%

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TABLE III. LIST OF ELECTRICAL TEST EQUIPMENT

Description	Manufacturer	Model	Calibration Weeks	Accuracy
Test Set, Insulation	Associated Research	414	52	
Scanner	Auto Data	3100A	52	
Scanner	Auto Data	3100A	52	
Voltmeter, Electronic	Ballantine Lab	300	17	0.2%
Voltmeter, Electronic	Ballantine Lab	300D	17	0.2%
Oven, Laboratory	Blue M Engr	POM206	17	+5°C
Oven, Laboratory	Blue M Engr	POM2068X	26	+5°C
Oven, Laboratory	Blue M Engr	CF2-7116A	26	+5°C
Voltmeter, Electronic	Boonton Electric	91CA	26	5% F.S.
Bridge, Capacitance	Boonton Electric	75A-58	26	+0.5%
Amplifier, Power	Boonton Radio	230A	26	
Stabilizing Unit	Chadwick Helmuth	201R	13	
Power Supply	Christie Elect	200K25	26	
Power Supply	Christie Elect	MH32-200K2	26	
Tester, Pulsed DC	Continental Devi	9509	26	1%
Power Supply	Continental Devi	95038	26	
Power Supply	Continental Devi	95098	26	
Tester, Pulsed DC Bet	Continental Devi	9503-1	26	1%
Tester, Beta	Continental Devi	MT13-3	26	1%
Tester, Semiconductor	Continental Devi	MTD01-1	26	1%
Tester, Semiconductor	Continental Devi	MTD02-1	26	1%
Tester, Voltage	Continental Devi	MTD17-3	26	1%
Amplifier	Dana Lab Inc	11	13	0.01% F.S.
Voltmeter, Digital	Dana Lab Inc	56005594	13	0.01% F.S.
Power Supply	Dressen Barnes	62-125	26	0.1%
Voltmeter, Digital	Dymec	24018	13	0.01%
Amplifier	Dymec	2411A	17	0.01%
Tester, Transistor	Eagle Pitcher	3307	26	
Stroboscope	Electric Braz	T5-80580	26	
Amplifier	Electro Metrolog	40	13	
Resistance Meas Syst	Electro Sci Ind	242A	26	>0.01%
Divider, Voltage	Electro Sci Ind	DV411	26	0.005%
Divider, Voltage	Electro Sci Ind	DV411	26	0.005%
Power Supply	Electronic Meas	212A	39	0.25%
Power Supply	Electronic Meas	C630AKM	26	0.25%
Accelerometer	Endevco Corp	2215	26	-1%+3
Hygro-Thermograph	Friez	594	26	
Bridge	General Radio	1607	26	
Inductor, Decade	General Radio	940D	26	-1.5%
Detector, Heterodyne	General Radio	DNT2	26	
Power Supply	General Radio	1201C	17	
Oscillator	General Radio	1209C	17	
Oscillator	General Radio	1215C	17	
Oscillator	General Radio	1218A	17	
Integrated Circuit Test System	Fairchild	4000M		0.1%
Scanning and Measurement System	TRW PAL	IICT		0.1%

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TABLE III.   LIST OF ELECTRICAL TEST EQUIPMENT (Continued)

Description	Manufacturer	Model	Calibration Weeks	Accuracy
Amplifier, Null Detec	General Radio	1232A	17	
Capacitor, Decade	General Radio	1419M	26	1%
Capacitor, Decade	General Radio	1422D	26	0.05%
Resistor, Decade	General Radio	1432M	26	0.05%
Resistor, Decade	General Radio	1432N	26	0.05%
Stroboscope	General Radio	1531A	17	
Bridge, Capacitance	General Radio	1611B	26	$\pm 1\%$
Bridge, Impedance	General Radio	1650A	26	$\pm 1\%$
Comparator, Impedance	General Radio	1605AM	26	
Variac, Metered	General Radio	W10MT3	26	
Bridge	Gertsch/Singer	CRB8	26	
Ratiotron	Gertsch/Singer	RT60	52	
Standard, Ratio	Gertsch/Singer	1011R	52	10 ppm
Ammeter, DC	Greibach Instr	500	17	0.5%
Voltmeter, DC	Greibach Instr	500	26	0.5%
Power Supply	Harrison Labs	3412	26	0.04%
Power Supply	Harrison Labs	808A	39	0.02%
Power Supply	Harrison Labs	808A	39	0.02%
Power Supply	Harrison Labs	808A	39	0.02%
Power Supply	Harrison Labs	808A	39	0.02%
Power Supply	Harrison Labs	809A	26	0.04%
Power Supply	Harrison Labs	809A	26	0.04%
Power Supply	Harrison Labs	809A	26	0.04%
Power Supply	Harrison Labs	814A	26	0.06%
Power Supply	Harrison Labs	814A	26	0.06%
Power Supply	Harrison Labs	855B	26	0.06%
Power Supply	Harrison Labs	855B	26	0.06%
Power Supply	Harrison Labs	865B	26	0.02%
Power Supply	Harrison Labs	865B	26	0.02%
Power Supply	Harrison Labs	865B	26	0.02%
Power Supply	Harrison Labs	865B	26	0.02%
Power Supply	Harrison Labs	865C	26	0.04%
Power Supply	Harrison Labs	865C	26	0.04%
Power Supply	Harrison Labs	890A	26	0.014%
Power Supply	Harrison Labs	890A	26	0.014%
Power Supply	Harrison Labs	6521A	26	0.1%
Power Supply	Harrison Labs	6522A	26	0.1%
Generator, Sq-Wave	Hewlett Packard	211A	26	
Generator, Pulse	Hewlett Packard	215A	17	0.5%
Analyzer, Distortion	Hewlett Packard	330B	39	3%
Source, Noise, VHF	Hewlett Packard	343A	26	
Voltmeter, Vacuum Tub	Hewlett Packard	400H	17	0.2%
Voltmeter, Vacuum Tub	Hewlett Packard	400H	26	0.2%
Voltmeter, Vacuum Tub	Hewlett Packard	410B	26	0.3%
Meter, Calorimetric	Hewlett Packard	434A	17	
Counter, Electronic	Hewlett Packard	523D	17	± 1 count
Generator, Signal, VHF	Hewlett Packard	608D	17	0.1%

TABLE III. LIST OF ELECTRICAL TEST EQUIPMENT (Continued).

Description	Manufacturer	Model	Calibration Weeks	Accuracy
Generator, Signal, UHF	Hewlett Packard	612A	26	0.1%
Oscillator, Test	Hewlett Packard	650A	26	0.3%
Power Supply	Hewlett Packard	716B	26	
Slotted Line, Coaxial	Hewlett Packard	806B	26	
Carriage	Hewlett Packard	809B	26	
Oscillator, LF	Hewlett Packard	200CD	17	0.1%
Counter, Electronic	Hewlett Packard	5245L	26	
Counter Plug-In	Hewlett Packard	5253B	13	
Counter Plug-In	Hewlett Packard	5265A	13	0.01% F.S.
Attenuator, Variable	Hewlett Packard	X382A	26	
Mount, Detector	Hewlett Packard	X485B	26	
Ammeter	Hexem Inc	120	17	0.1%
Ohmmeter	Indus Instr	L7	26	
System, Vibration	International TT	None	26	
Attenuator	Kay Electric	30-0	26	
Voltmeter, Electronic	Keithley Instr	200B	17	0.2%
Power Supply	Kepco Labs	SM75-5M	26	0.2%
Power Supply	Kepco Labs	SM75-5M	26	0.2%
Voltmeter, Electronic	Kintel	202B	17	0.1%
Amplifier, AF	Knight, James	93SZ655	17	
Amplifier, Power	MC Intosh Lab	M1200E	17	
Power Supply	Metrolog	501F400	26	
Meter, Wave	Microlab/FXR	H415A	13	
Isolator, X Band	Micromega Corp	XM120	26	
Isolator, X Band	Micromega Corp	XM120	26	
Recorder, Signal Data	Moseley, F. L.	1	17	
Oven, Vacuum	Natl Appliance	2165	26	
Amplifier	Non Linear Sys	144	17	
Printer	Non Linear Sys	155	26	
Printer	Non Linear Sys	155	13	
Adapter	Non Linear Sys	180	52	
Voltmeter, Digital	Non Linear Sys	M25	13	0.01%
Voltmeter, Digital	Non Linear Sys	V34B	13	±1 Digit
Power Supply	Panoramic/Singer	PS12	17	
Analyzer, Spectrum	Panoramic/Singer	SB12B	17	
Power Supply	Philbrick, G.A.	R300	26	
Power Supply	Philbrick, G.A.	R100B	26	
Power Supply	Philbrick, G.A.	R100B	26	
Camera, Still Picture	Photograph Ins	CCP5000	52	
Power Supply	Power Design	605	26	0.1%
Power Supply	Power Design	605	26	0.1%
Power Supply	Power Design	605	26	0.1%
Power Supply	Power Design	605	26	0.1%
Amplifier, Standing W	PRD	277B	17	
Oven	Precision Sci	18	52	
Generator, Pulse	Rutherford	B7B	17	
Voltmeter	Sens Rsch/Singer	ESD	52	0.3%
Bridge, Impedance	Shallcross Mfg	638R	26	0.3%
Meter, Thermo	Simpson	388	17	1.5 Div.
Meter, Thermo	Simpson	388	17	1.5 Div.
Meter, Thermo	Simpson	389	26	1.5 Div.

TABLE III. LIST OF ELECTRICAL TEST EQUIPMENT (Continued)

Description	Manufacturer	Model	Calibration Weeks	Accuracy
Transformer, Voltage	Sola Elect	CVI	52	
Transformer, Voltage	Sola Elect	CVN	52	
Transformer, Voltage	Sola Elect	72111	17	
Transformer, Voltage	Sola Elect	23-25-210	26	
Transformer, Voltage	Sola Elect	23-25-210	26	
Transformer, Voltage	Sola Elect	23-25-220	52	
Transformer, Voltage	Sola Elect	23-25-220		
Oven, Laboratory	Statham Instr	BC4A	26	$+5^{\circ}C$
Temperature Chamber	Statham Instr	SD6-5-1-2	17	$\pm 1/4^{\circ}C$
Oscilloscope, Plug-In	Tektronix	H	17	
Oscilloscope, Plug-In	Tektronix	Z	17	
Oscilloscope, Plug-In	Tektronix	82	17	
Oscilloscope, Plug-In	Tektronix	CA	26	
Meter, LC	Tektronix	130	17	3%
Amplifier	Tektronix	131	17	
Adapter, High Current	Tektronix	175	17	
Tester, Time Switch	Tektronix	290	26	
Tester, Time Switch	Tektronix	291	26	
Oscilloscope, Plug-In	Tektronix	3B3	17	0.3%
Oscilloscope	Tektronix	564	17	
Oscilloscope	Tektronix	567	17	
Oscilloscope	Tektronix	575	17	
Oscilloscope, Plug-In	Tektronix	6R1	17	
Generator Sine-Wave	Tektronix	190A	17	
Oscilloscope, Plug-In	Tektronix	3A72	17	
Oscilloscope, Plug-In	Tektronix	3S76	17	
Oscilloscope, Plug-In	Tektronix	3T77	17	
Oscilloscope	Tektronix	545A	13	
Oscilloscope	Tektronix	585A	13	
Chamber, Temperature	Tenney Engr	TM3UF1009	26	
Generator, Pulse	Texas Instr	6607RX	17	
Meter, Vom	Triplett	630	17	1.5%
Meter, Vom	Triplett	630	17	1.5%
Meter, Vom	Triplett	630	17	1.5%
Recorder, Signal Data	Varian Assoc	G11A	26	
Recorder, Signal Data	Varian Assoc	G11A	26	
Voltmeter	Weston Instr	931	52	0.25%
Ammeter	Weston Instr	931	52	0.25%
Meter, Milli	Weston Instr	931	52	0.25%
Ammeter	Weston Instr	931	52	0.25%
Ammeter, DC	Weston Instr	931	52	0.25%

5. Ethylene Oxide Exposure

In the recommended test program, sterilization of part types will be accomplished in four treatment groups to permit evaluation of the ethylene oxide exposure. One group will be subjected to all procedures of JPL Specification VOL-50503-ETS except that no ethylene oxide will be applied. This treatment group sample will be used as a control group. A second group of parts will be subjected to all procedures of VOL-50503-ETS with ethylene oxide applied at the specification pressure of 5 psi. The third and fourth treatment groups will be subjected to the same sterilization except that the ethylene oxide will be applied at 12 and 18 psi, respectively, thus permitting evaluation of greater exposure.

The recommended ethylene oxide exposure would be conducted in a chamber capable of maintaining the prescribed concentration of ethylene oxide for 28 hours. The chamber would be equipped with pressure, humidity, and temperature gauges and a heat exchanger for preheating and humidifying the air and ethylene oxide-Freon 12. A flow diagram of the operation of the chamber is shown in Figure 2. The chamber would be loaded with components so that the chamber volume would be three times that of the test parts.

At the start of the exposure, the sterilant gas will be sampled and analyzed for ethylene oxide concentration with a gas chromatograph (Beckman CG-2A) equipped with a 12-foot dioctyl sebacate-U con 50HB-200 column and a thermal conductivity detector.

The rates of reaction of ethylene oxide of concern in this program are influenced by temperature, concentration of the reacting substances, and rate of diffusion of the gas.

Many reactions in the neighborhood of room temperature approximately double or treble their velocity for a 10° rise. A quantitative expression for this is given by the Arrhenius equation:

$$k = se^{-\Delta H_a/RT}$$

where

$$s = \text{frequency factor} = \frac{RT}{Nh} e^{\Delta S_a/R}$$

ΔH_a = heat of activation

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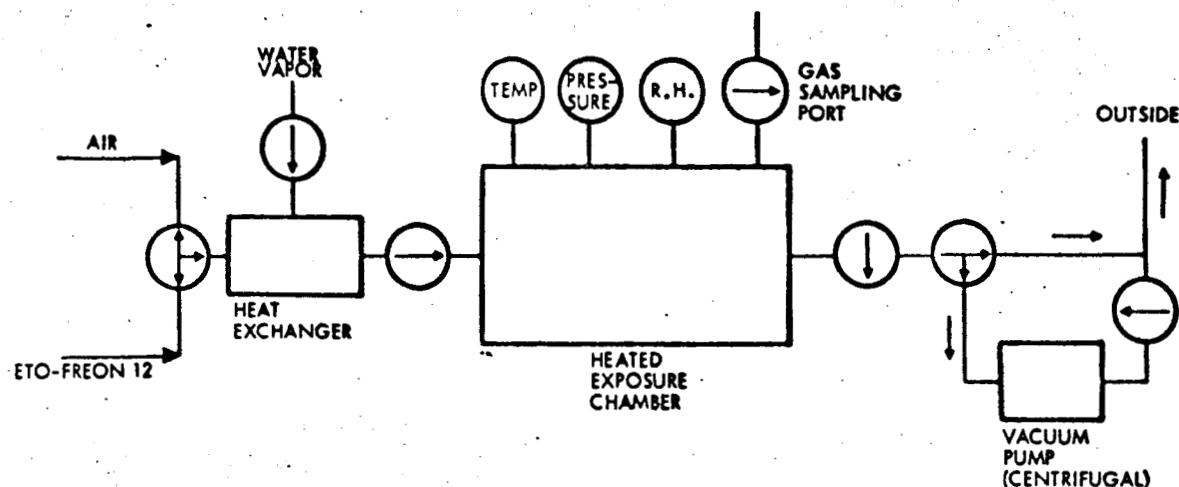
Figure 2. Flow Diagram of Ethylene Oxide Exposure Chamber

R = gas constant

T = temperature

k = reaction rate constant

The energy required for activation is usually the chief factor in determining the speed of the reaction.

The relationship between concentration of reactants and reaction rate is expressed by the following equations:

First order reaction:

$$\frac{-dc_A}{dt} = kc_A$$

Second order reaction:

$$\frac{-dc_A}{dt} = kc_A c_B$$

Third order reaction:

$$\frac{-dc_A}{dt} = kc_A c_B c_C$$

where

c = concentration of the reacting materials

A, B, C = reactants

t = time

k = reaction-rate constant

$\frac{-dc}{dt}$ = rate at which the concentration decrases

Very likely, the potential reactions involve two or more different reactions taking place at the same time so that the expression for an over-

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all reaction is some resultant of the above rate expressions. Among the reactions which could occur are (1) consecutive reactions, (2) reverse reactions, and (3) competing reactions. These may be shown by:

(1) $A \rightarrow B \rightarrow C$

(2) $A_2 + B_2 \rightleftharpoons 2AB$

(3)

$$A \begin{array}{c} \xrightarrow{+B} AB \\ \xrightarrow{+C} AC \end{array}$$
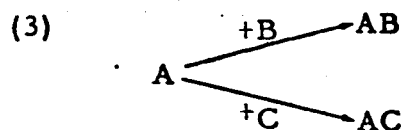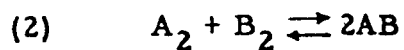
The reaction rate when the overall reaction includes consecutive first-order reactions with reverse reaction, illustrated in Figure 3, is:

$$A \xrightarrow{k_1} B \underset{k_3}{\overset{k_2}{\rightleftharpoons}} C$$
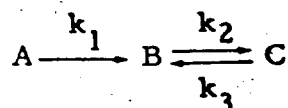
where

$k_1 = 0.1$

$k_2 = 0.1$

$k_3 = 0.05$
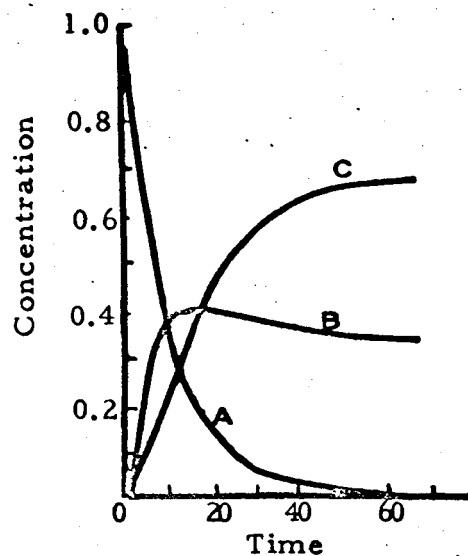
Figure 3. Consecutive First-Order Reactions with Reverse Reaction $A \rightarrow B \rightleftharpoons C$

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It can be seen that when the concentration of A is high, the re-
action proceeds rapidly. As concentration decreases, the rate correspond-
inly decreases.

A zero-order reaction results and the rate is unaffected by the con-
centration when some other limiting factor is present, such as rate of dif-
fusion in certain surface reactions:

$$- \frac{dc_A}{dt} = k'$$

Diffusion rate is affected by temperature and concentration.

From these analyses, it follows that two possible ways of speed-
ing up the reactions leading to degradation of the component parts are:

    1. Increase the temperature

    2. Increase the concentration of ethylene oxide

The temperature has already been increased 12° by Specification
VOL-50503-ETS over the expected sterilization temperature of $38^\circ C$. This
is sufficient to approximately double the rate of certain reactions. To in-
crease the temperature further requires consideration of the possibility of
initiating reactions that would not occur at lower temperatures, thus adding
a new degradation mode.

The concentration of ethylene oxide can be raised by increasing
the ratio of ethylene oxide to Freon 12 in the sterilant mixture (which is
commercially supplied as 12% ethylene oxide — 88% Freon 12) or by in-
creasing the pressure of the mixture. Increasing the ethylene oxide ratio
may produce a better result, since this reduces the concentration of the
inert diluent Freon 12, but it would also render the mixture flammable,
constituting a handling hazard. Increasing the pressure also tends to aug-
ment diffusion by increasing the pressure gradient.

6. Heat Sterilization

Heat sterilization would be accomplished as prescribed (paragraphs 4.3.2 and 4.3.7 of Specification VOL-50503-ETS). An oven capable of maintaining a nitrogen atmosphere and a temperature distribution of $\pm 2^{\circ}C$ at $135^{\circ}C$ would be utilized. A flow diagram of its operation is presented in Figure 4. The oven would be equipped with eleven probes to establish the temperature distribution within the chamber. Analysis of the oven atmosphere would be conducted with the gas chromatograph.
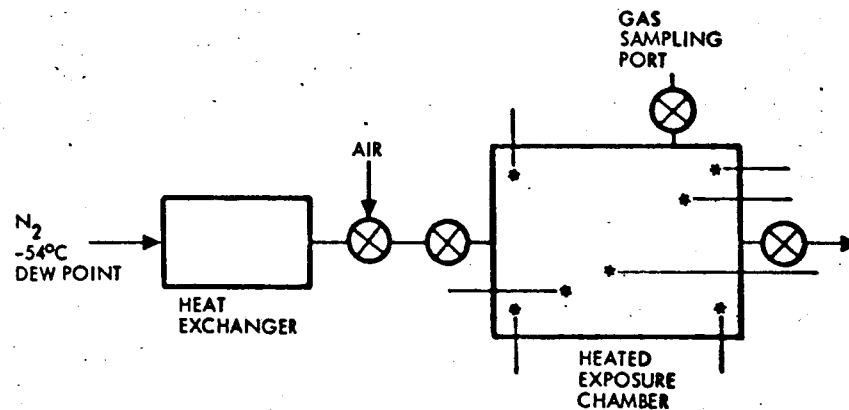
* TEMPERATURE PROBES (11 LOCATIONS)

X   VALVES

Figure 4. Flow Diagram of Heat Sterilization Set-Up

7. Controlled Storage Conditions

During the controlled storage time periods of the test program, the test parts will be maintained under conditions of bonded storage. All parts will be contained in locked cabinet storage in a filtered air environment at a temperature of $25°C \pm 4°$ at relative humidity under 50%. These conditions will be maintained during the nine-month storage period of the long-term tests, as well as during the period following initial inspection and burn-in before the start of the long-term test.

Test measurements will also be made in these controlled environments which are normally maintained in the laboratory.

8. Failure Analysis

Failure analysis will be performed on all parts which fail during the performance of the test program. The number of parts which will be subjected to these procedures is not expected to be large and not to exceed 5%. Test conditions throughout the program will be those which the parts are expected to see during mission conditions. Electrical loading will be at anticipated derated design levels and at the maximum rated levels, both of which are well below stress loadings. Temperatures likewise will not be severe, representing operating temperature in the spacecraft equipment and maximum rated temperature. Ethylene oxide exposure and heat sterilization exposure are not expected to result in more than a small number of failures, if any, since the test parts have been selected for ability to withstand these procedures. The entire test program is designed to prove the hypothesis that the test parts will withstand the complete test cycle without degradation resulting from sterilization procedures.

Three types of discrepancies will be considered as failures in the course of this program. These will be catastrophic, parameter drift, and degraded test treatment groups. Catastrophic failures are those in which a part becomes completely inoperative as a result of an electrical open, short, or similar malfunction. For the most part, these will be random failures in this test program. Parameter drift beyond acceptable limits will be considered as a failure in each instance. Parametric drift limits will be defined for each part type prior to the start of the testing. The most significant failure types, however, which may occur during the

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testing will be of the degraded treatment group type. Any of the sterili-
zation treatment groups which show a statistically significant difference
in performance, compared with either the control or other sterilization
groups, should be subjected to a complete failure analysis to determine
the cause and to establish the need for corrective action or other recom-
mendations.

It is planned to conduct thorough failure analyses in accordance
with standard procedures in effect at TRW Systems. Each failed part
will be subjected to thorough external visual examination under magni-
fication for gross defects such as cracks, distortion, discoloration, evi-
dence of external damage, shrinkage, porosity, and similar discrepant
conditions. Leakage tests will be performed on hermetically sealed parts.
Where indicated, parts will be X-rayed in three axes. All defects will
be photographed. Electrical tests will be performed to verify the failure
mode. Following external analysis, the failed part will be opened and a
thorough internal examination will be made. Parts which cannot be opened
because of their construction will be sectioned at significant planes and
examined using metallographic techniques, including magnification up to
2000X. These metallographic techniques involve encapsulation of the
specimen in clear plastic, sectioning, grinding, and lapping to reveal the
cross section areas of interest. If internal examination reveals areas
which are contaminated or otherwise attacked as a result of ethylene oxide
exposure, these areas will be analyzed as appropriate. Techniques which
are available include residual gas analysis, X-ray diffraction, electron
microscopy, emission spectrography, mass spectrography and gas chrom-
otography, and wet chemical analysis.

Results of failure analyses will be required as quickly as possible
in order to incorporate the findings into either the test program design or
final report design decisions. For this reason, it will be necessary to
conduct the analyses expeditiously, first determining whether the failure
is of major significance to the program and secondly determining detailed
information useful for recommended corrective action.

D. TEST PHILOSOPHY

The entire test program has been designed to prove the initial hypothesis that the test parts will not be degraded by exposure to ethylene oxide sterilization. This proof will be furnished by submitting sterilization treatment groups of parts and control samples to various sets of conditions simulating the Voyager-Lander mission. If no statistically significant difference is found among the treatment groups, by measurement of the sensitive electrical parameters of the test parts, then the hypothesis is considered to be proved beyond further doubt.

In Figure 5, parameter drift and failure rate for a particular part are shown versus time in Lander duty-cycles. Relationships are hypothesized for the general part type based on engineering and statistical knowledge of failure and drift characteristics associated with these parts. It is accepted that the general part has a catastrophic failure rate independent of its drift characteristics. The lower portion of Figure 5 depicts this failure rate for a part exposed to different environments. As the severity of the environment increases, the failure rate increases and the start of wearout (increasing failure rate) begins sooner. Considering the high reliability of these parts, and in light of the time and effort associated with life testing, the realm of catastrophic failure rates for these parts will not be investigated.

The parameter drift portion of Figure 5 (upper portion) shows that a catastrophic parameter drift failure level exists for each critical parameter associated with a particular part. Curve 1 depicts a part reaction for room temperature at derated conditions. Good estimates for this stress condition can be found in component part literature. Curve 2 depicts the same part with added stresses of connections, packaging, and so on. The relationship between Curves 1 and 2 can be estimated quite accurately. Curve 3 is the same as Curve 2 with maximum rated temperature and maximum rated electrical load applied. This curve is analogous to the control group in the long-term tests which is subjected to procedures of Specification VOL-50503-ETS without ethylene oxide applied and operated at the maximum rated temperature and electrical load exposed to twice the Lander duty cycle. Curve 4, except for the added ethylene oxide stress, is identical

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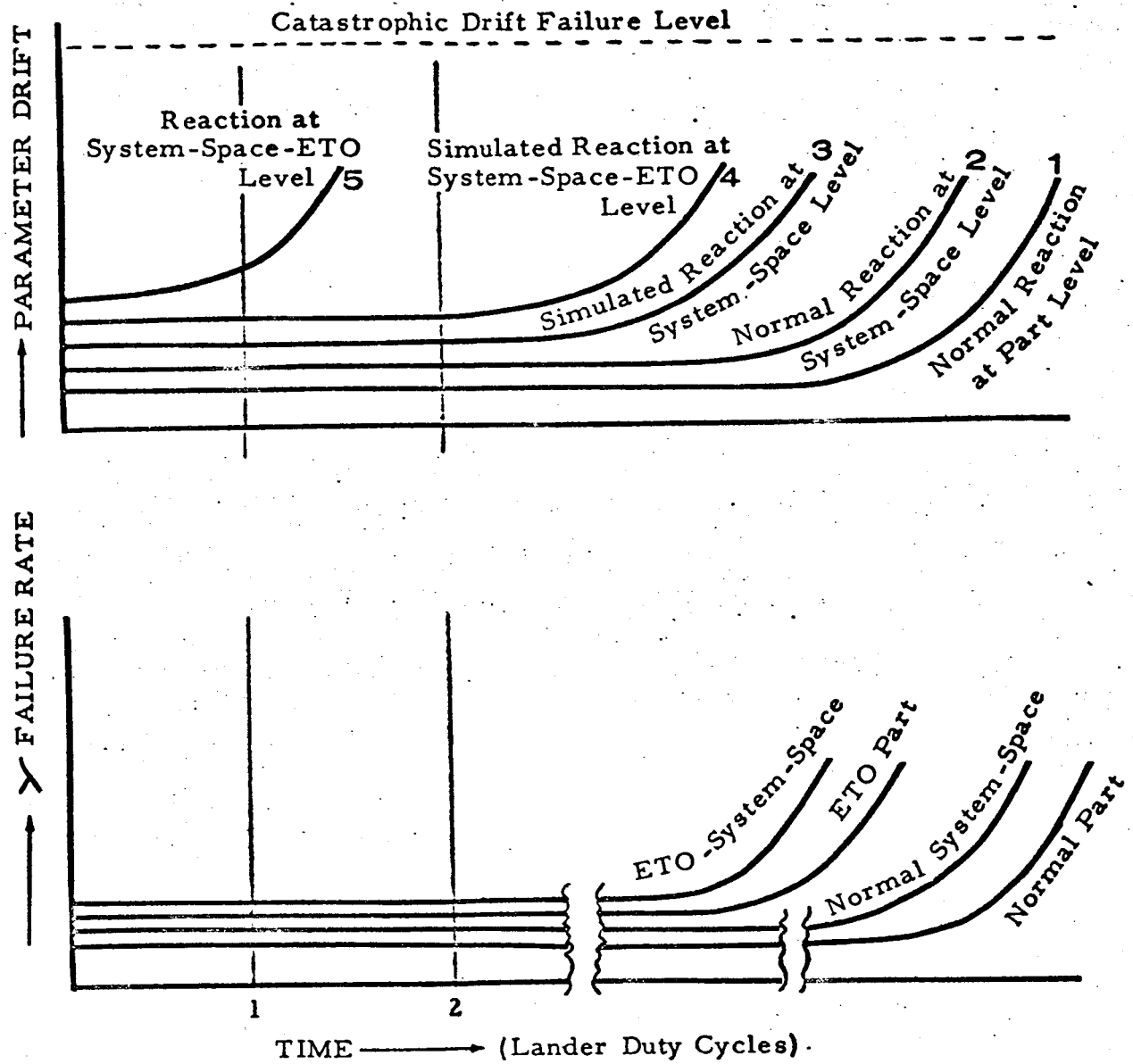
Figure 5. Parameter Drift and Failure Rate Curves for Particular Parts

to Curve 3 and is analogous to the spec group in the long-term tests
which is subjected to VOL-50503-ETS sterilization with ethylene oxide
at specification pressure and operated at maximum rated temperature
and electrical load.

The primary test of the hypothesis is for a significant difference be-
tween Curves 3 and 4, with the philosophy that if no significant difference
is found statistically, then a situation such as Curve 5 cannot exist. In
the tests, the specimens representing the maximum rated temperature
and maximum rated electrical loadings will constitute two-thirds of the
units. If a significant difference is found between Curves 3 and 4, then
the supporting data groups (one-third of the specimens subjected to anti-
cipated operating temperature and derated electrical loading) will be
analyzed to determine the sensitivity of degradation.

E. STATISTICAL DESIGN AND ANALYSIS

The statistical design to be employed in Phase III will embody extreme simplicity in that concepts of randomization, replication, and statistical control will be the guide lines which determine quality of information extracted from such a program. Normally, an analysis of variance technique is considered as the optimum decision-making approach because the tools for sound experimentation (experimental pattern, planned grouping of randomization, replication) are easily accessible in cookbook form and the net result is a neat comparison of mean values for significance. The analysis of variance approach, however, presupposes a knowledge of the distribution function of the experimental units which means that certain criteria must be met in order for the significance tests to be valid. In practical applications we never fully meet the necessary requirements for analysis of variance and it becomes a trade-off in that the requirements are relaxed (if they are not too far off) to take advantage of economy, conciseness, and wide range of applicability of conventional designs.

All experimental designs are handled generally in the same manner with respect to the statistician's role in determining a considered course of action aimed at answering one or more carefully framed questions. The presentation of all facets involved in the experiment will proceed according to the following order: (1) statement of objectives, (2) description of experiment, and (3) analysis of the results. It can be seen from the part types to be tested and the associated parameters to be measured, that the magnitude of the experiment is quite large. For the sake of simplicity, and ease of presentation, reference will be made only to a single parameter for a given part type (i.e., all parameters of all part types will be treated in the same manner.) The representative part type will be designated as "P" and the associated representative parameter to be measured as "p".

1. Statement of Objectives

The objectives will clearly be established before proceeding with the experiment. There will be no attempt to develop new modeling techniques but rather interest shall be centered about tests of significance.

The primary interest is degradation of physical and electrical character-
istics of part P, indexed by parameter p, as a result of exposure to ETO
in accordance with the JPL sterilization specification. The statement
of objectives will be expanded by treating the following subject matter:
(a) expected achievements, (b) experimental philosophy, and (c) defini-
tion of degradation.

a. Expected Achievements

Assuming that the total number of part types is 35 and the
average number of indexed parameters per part type is 4, then, in
actuality, there are 140 distinct and unrelated populations (although
within a P, the p's will have some correlation which will be assumed so
small that it can be ignored). By selecting the appropriate test of
significance, by determination of appropriate sample size, and by the
application of rigid statistical controls on the conduct of the test, it
will be determined whether or not each of the 140 populations is de-
graded by exposure to ETO. If degradation is found in any parameter,
failure analysis techniques will be recommended to explicitly relate
the ETO effect to the observed degradation. The worst case profile of
the Voyager-Lander mission will govern the test philosophy with re-
spect to experimental test time. Exact test time hours are discussed
elsewhere in this report.

b. Experimental Philosophy

The test to be conducted are not concerned with failure
rates and/or reliability per se. Within the scope of test time and stresses
to be applied, it is expected that no catastrophic failures will occur.
Occurrence of a random failure would not deter the course of action,
assuming it can establish that such a failure is not attributable to the
effects of ETO. The approach is basically to replicate p under heat
sterilization and ETO decontamination environments as outlined in JPL
specification VOL-50503-ETS, and to replicate p under the same speci-
fication conditions with the exception of the ETO application. This es-
tablishes a spec group and a control group (non-ETO) as related to a
single parent population . Any stresses applied to these two groups will
cause p to change. The variable of concern will be the absolute

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value of relative change, or $\left|\dfrac{p' - p_0}{p_0}\right|$ where p prime is the parameter

value after a specified stress and p_0 is the initial parameter value. Thus, if the sample size happens to be 50 and the same stress is simultaneously applied to both groups, the effect of the stress would be indexed as shown above and would result in 50 values for the spec group and 50 values for the control group. The two groups will then be compared statistically to see if the spec group differs significantly from the control group.

    c.   Definition of Degradation

Electrical degradation of parameter p will be defined as follows: "If the control group on p is compared with the spec group on p, after a specified stress has been applied to both groups simultaneously for a specified length of time, and the test statistic denotes the groups as being statistically different, then the condition of degradation exists."

Assuming degradation is found in some parameters, it will be duly noted and the failure analysis techniques will be recommended to define the cause and mode of degradation. In order to give the above definition more meaning, the time and stress elements will be associated with the Voyager-Lander profile to demonstrate a built-in safety margin of the definition. This is saying, in essence, that it is not enough to merely recreate the Voyager-Lander time-stress profile. The part environment cannot be created satisfactorily in the lab, so margins must be allowed for unknown stresses that these parts will be subjected to in their duty cycle, plus the stresses due to normal handling in building a module, sub-assembly, assembly, etc.

If there is an ETO effect on part P, parameter p, then some assumptions should be made as to the nature of the effect on failure rate in the parameter drift sense (as opposed to catastrophic failure). In the absence of a definitive relationship of failure rate and parameter drift, drift failure will be announced as being indicated if a statistically significant difference between the control and spec groups is found under the accelerated aging conditions of maximum temperature, maximum load, and two times the Lander duty cycle (time oriented once Mars is reached).

2. Description of the Experiment

    With the statement of objectives defined, an experimental design will be outlined which will achieve these objectives through statistical tests of significance. Having already adjudged conventional analysis of variance techniques as unsuitable for application to this type of data, distribution free and non-parametric techniques for the appropriate experimental design have been investigated. It only remains to define the experimental test design in terms of design pattern, sample sizes, treatment applications, conduct of test, etc. The description of the experiment will evolve through a discussion of the following topics: (a) experimental area, (b) experimental pattern, (c) experimental material, and (d) size of the experiment.

    a. Experimental Area

    This can be thought of as the scope of the planned experiment. The experimental area of interest is time oriented in that the Voyager-Lander duty cycle is the "experimental plot" in which the treatments are applied, treatment effects allowed to grow, and then ultimately to measure these effects for comparison purposes. Statistical controls on the conduct of the test establish the homogeniety of the experimental plot, which is a very necessary requisite. From the experimental plot, yields are obtained, which will be measured results of treated units. These measured results will be taken in a controlled environment of temperature and humidity because many of the parameters are sensitive to even small changes in these two environments. Also, no monitor equipment will be calibrated during the stress portion of the program (parameters will be monitored several times during this period).

    b. Experimental Pattern (Pilot Test)

    From an examination of existing distribution-free statistical tests, two methods appear to have the qualifications for making the necessary group comparisons for statistical significance. One of the two methods will be selected and the basis for this selection will be a pilot test conducted prior to the main experiment. These two tests are the Mann-Whitney test and Kolmogorov-Smirnov test. A brief description of each test is given below and a pictorial description of each test is given in Figure 6.

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Mann-Whitney (Same Shape Parameter)
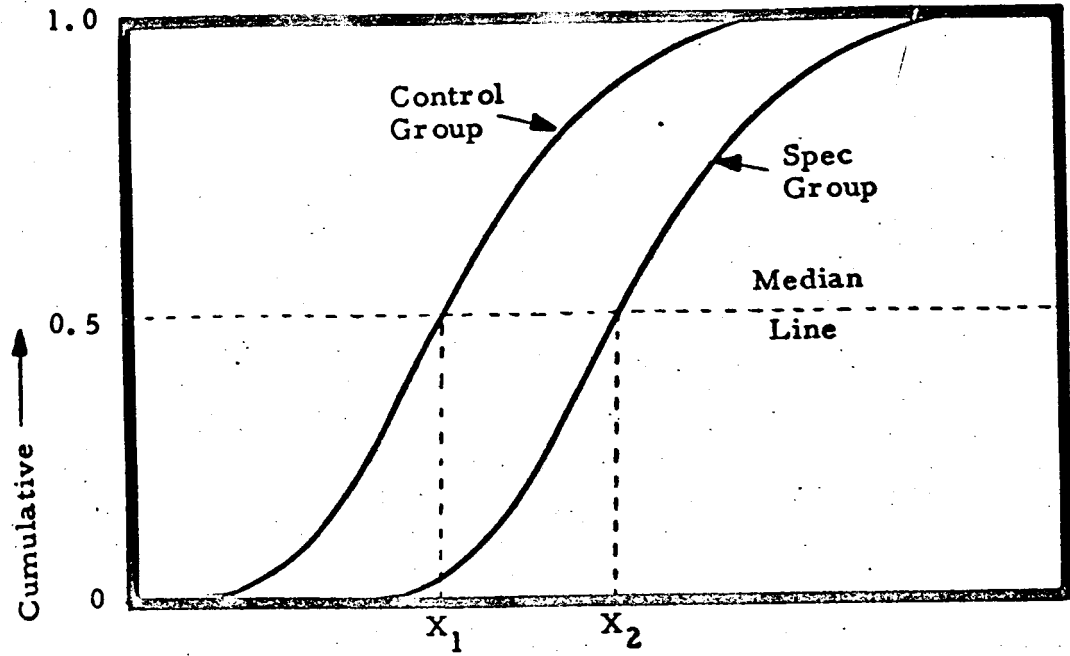
$$X = \left| \frac{p' - p_o}{p_o} \right| \longrightarrow \text{Hypothesis: } X_2 - X_1 = 0$$

Kolmogorov-Smirnov (Independent of Shape Parameter)
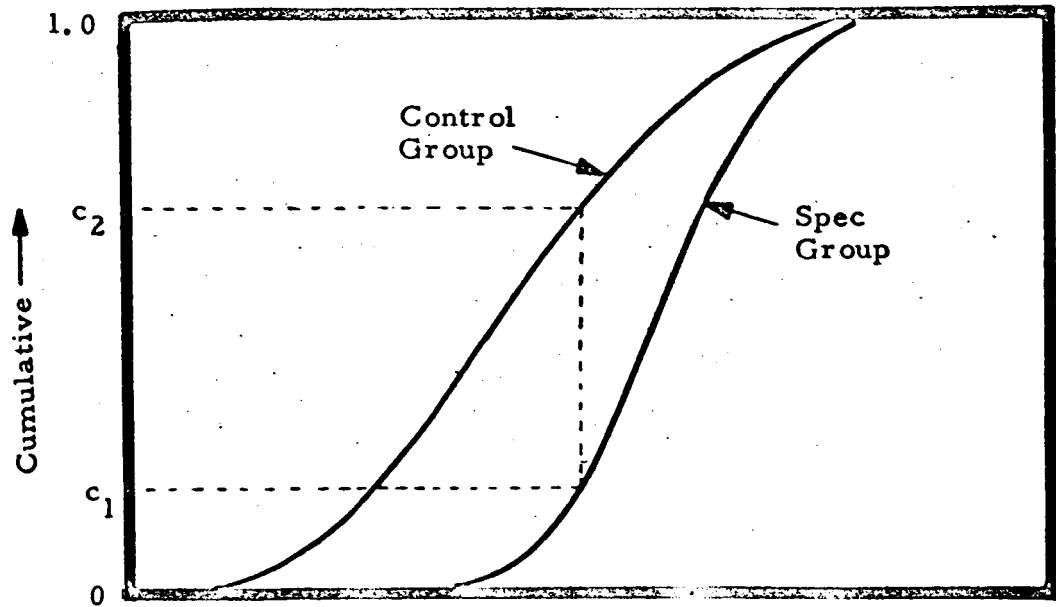
$$X = \left| \frac{p' - p_o}{p_o} \right| \longrightarrow \text{Hypothesis: Maximum } (c_2 - c_1) = 0, \text{ overall } X$$

Figure 6. Pictorial Description of Experimental Patterns

Mann-Whitney

Assumptions: a) Sampling is random

b) Observations are independent

c) Populations are continuously distributed

d) Populations have identical forms

Test Hypothesis: Null hypothesis on medians

Efficiency: 95% as efficient as analysis of variance on known normal data.

Kolmogorov-Smirnov

Assumptions:

a) Sampling is random

b) Observations are independent

c) Populations are continuously distributed

Test Hypothesis: Null hypothesis on parent populations

Efficiency: Unknown

The selection procedure will be to conduct the pilot test on a limited number of part types, observe the form of the cumulative distributions of $\left| \dfrac{P' - P_0}{P_0} \right|$ for both the spec and the control groups, and apply mathematical judgment as to whether or not the populations have identical forms. If they can be adjudged to satisfy assumption d) under Mann-Whitney, then this test method is selected because it is the more desirable of the two tests if given an option. The alternative to this selection will be the Kolmogorov-Smirnov test.

The pilot test indicated above will be an abbreviated matrix test with treated groups subjected to operating stresses for a minimum duration of three weeks according to the following chart:

PILOT TEST SAMPLE SIZES AND OPERATING STRESSES				
		Load 1		Load 2	
		Temp 1	Temp 2	Temp 1	Temp 2
STERILIZATION TREATMENTS	No Stress	—	5	—	5
	Control	5	10	10	20
	Spec	5	10	10	20
	Pressure 1	—	5	—	5
	Pressure 2	—	5	—	5

NOTES:

No Stress = After acceptance for the test with no sterilization

Control = Sterilization in accordance with JPL Specification VOL-50503-ETS omitting ethylene oxide application

Spec = Sterilization in accordance with JPL Specification VOL-50503-ETS with no deviations (ethylene oxide at 5 psi)

Pressure 1 = Sterilization in accordance with JPL Specification VOL-50503-ETS except that ethylene oxide application is performed at 12 psi

Pressure 2 = Sterilization in accordance with JPL Specification VOL-50503-ETS except that ethylene oxide application is performed at 18 psi

Load 1 = Derated electrical operating loading

Load 2 = Maximum rated electrical operating load

Temp 1 = Nominal operating temperature

Temp 2 = Maximum rated operating temperature

(Absence of a number in a chart cell indicates that the particular combination of treatment-operating stress will not be investigated)

Figure 7. Pilot Test Matrix Chart

This pilot test, in addition to furnishing a look at population distributional characteristics, is intended to have stress levels high enough (pressure levels 1, 2) to force noticeable degradation in these parts due to ETO activity. A failure analysis of this degradation will be used as a guideline in analyzing degradation results in the main experimental test if it is found to exist. The analysis of the pilot test will seek results that have been forced into the matrix. For example, the analysis is started by comparing the results of pressure 2 with spec and pressure 2 with control at maximum conditions of load and temperature. If this provides the desired results then the remainder of the matrix can be discarded.

     c. Experimental Material (Long-Term Tests)

Of primary concern is the identification and application of treatments. Based upon the results of the pilot test, three treatments will be identified — control, spec, and pressure. Each part type will carry an equal number of units within each of the three treatment groups. A time profile of the sequence of events is as follows:

DESCRIPTION OF EVENTS

Sterilization Treatments Applied

9 Months of Storage Life
Simulating Time to Reach Mars

12 Weeks of Stress Life
Simulating Lander Duty Cycle After Reaching Mars
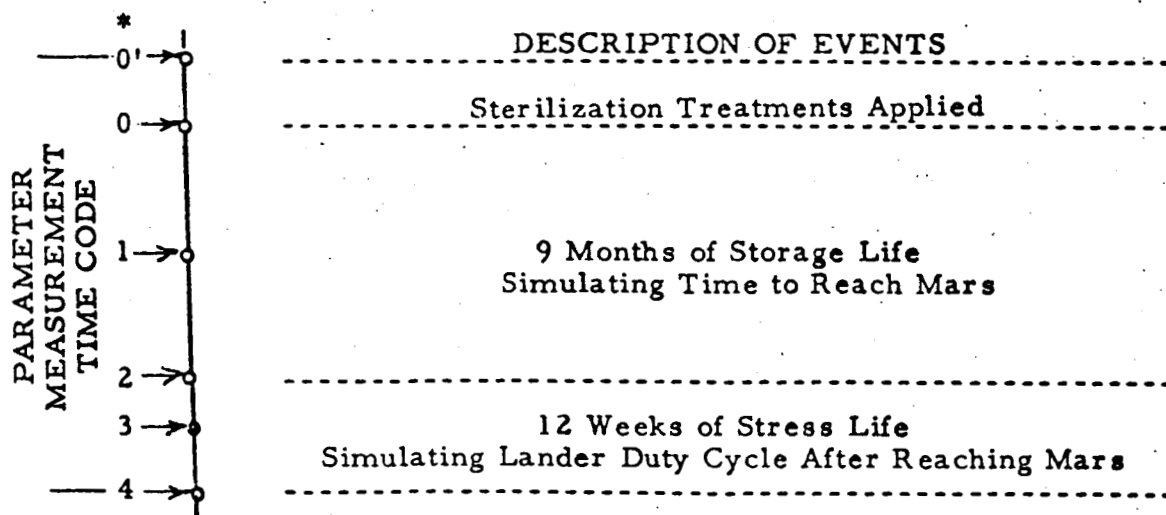
Figure 8. Long-Term Test Sequence Chart

When time code 2 is reached, and after the parameters are monitored, each treatment group will be partitioned into two subgroups, composed of 1/3 and 2/3 of the units respectively. The stress applied from time code 2 through time code 4 will be as follows:

	Derated Operating Stresses	Maximum Rated Stresses
Control Spec Pressure	1/3 of Units	2/3 of Units

d. Size of the Experiment (Long-Term Tests)

Determination of sample size is the establishment of the number of experimental units (for each part type) in each of the three treatment groups. The sample size will be determined for the Kolmogorov-Smirnov test method and will be deemed adequate for the alternative Mann-Whitney test method (for the same sample size, the Mann-Whitney test is more powerful than the Kolmogorov-Smirnov test). The limiting distribution of the Kolmogorov-Smirnov statistic leads to a simple choice of sample size given by the sample size formula in a Handbook of Statistical Tables by D. B. Owen, page 439.[26] With reference to Figure 6, the sample size equation necessitates an alternate hypothesis to $c_2 - c_1 = 0$, which will be designated as $c_2 - c_1 = .35$, which is an arbitrarily selected value. If a 10% chance is allowed of accepting the alternate hypothesis when the null hypothesis is true, and if a 5% chance is allowed of accepting the null hypothesis when the alternate hypothesis is true (types I and II error), then the sample size equation results in a total of 50 units per part type per treatment. This fills the requirement for the units that receive maximum rated stresses after time code 2 is reached. An additional 25 units per part type per treatment will be required for normal operating stress conditions after time code 2 is reached. This gives a total of 75 units per part type per treatment or 225 units per part type.

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		PART TYPES								
		1				P			35		
TIME CODE	TREATMENT CONDITIONS	Parameter			...	Parameter	....	Parameter		
		1	2	3		P		1	2	3
0'	Untreated					225				
0	Control					75				
	Spec					75				
	Pressure					75				
1	Control					75				
	Spec					75				
	Pressure					75				
2	Control					75				
	Spec					75				
	Pressure					75				
3	Control $\frac{1}{2}$	--				$\frac{50}{25}$	--			--
	Spec $\frac{1}{2}$	--				$\frac{50}{25}$	--			--
	Pressure $\frac{1}{2}$	--				$\frac{50}{25}$	--			--
4	Control $\frac{1}{2}$	--				$\frac{50}{25}$	--			--
	Spec $\frac{1}{2}$	--				$\frac{50}{25}$	--			--
	Pressure $\frac{1}{2}$	--				$\frac{50}{25}$	--			--

Figure 9. Treatment Groups and Sample Size for Long-Term Test

The pilot test will require a total of 120 units per part type with 11 part types being investigated in this portion of the program.

3. <u>Analysis of Results</u>

The analysis of results is functional in that the decision function is merely a determination as to the acceptability of a hypothesis, through a mathematical treatment of collected data. The hypothesis is, in all cases, "that there is no degradation due to the effect of ETO treatment". In order to assess the manner in which the data is manipulated (according to a predetermined plan) to arrive at the decision as to acceptance (or rejection) of the hypothesis, the following subject matter will be discussed: (a) decision function, (b) computer algorithms, and (c) interpretation of results.

It is necessary to introduce Figure 9 for a comprehensive look at treatment groups, sample size, and the comparisons involved in a test plan of this magnitude. Figure 9 follows typical parameter "p" of typical part type "P" through the time codes as a function of sample size for each treatment condition encountered. This is "step stress" application in that the same units are stepped sequentially from time codes 0' to time code 4.

a. Decision Function

This will be strictly a go, no-go criteria by which a critical value (u) is computed and compared with an observed difference. If the observed difference exceeds u a significant difference is announced; if it does not there is no difference. Confidence limits, standard errors, variance estimates, etc. are not of interest. The only interest is in the testing of hypothesis. The comparisons for parameter "p", part type "P" that will be performed are outlined as follows:

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Time Code	Condition	Test	Sample Size
0'-0	Treatments Applied	Control vs Control	75
		Spec vs Spec	75
		Pressure vs Pressure	75
0-1	1/2 Shelf Life	Control vs Spec	75
0-2	Full Shelf Life	Control vs Spec	75
0-3	1/2 Active Duty Cycle	Control vs Spec	50
0-4	Full Active Duty Cycle	Control vs Spec	50

Treatment comparisons involving the pressure treatment
groups are omitted as are comparisons involving the low stress sub
groups (sample size 25) on control vs spec for the active duty cycle
portion of the time codes. If a hypothesis is refuted (indicating an ETO
effect) higher and lower stressed groups will be available (which had no
effect on the acceptance or rejection of the hypothesis) to be used for
making engineering judgments as to the magnitude and ramifications
of the statistically noted ETO effect.

    b.   Computer Algorithms

The data from the tests will be fed to the electronic
computer through tape or cards depending on the part type, and for
any one comparison (say control vs spec for 1/2 shelf life on parameter
p) a group of 75 X's will be calculated for control drift such that

$X_i = \left| \dfrac{P_1 - P_o}{P_o} \right|$. Similarly, a group of 75 Y's will be calculated for spec

drift such that $Y_i = \left| \dfrac{P_1 - P_o}{P_o} \right|$. The X and Y nomenclature is used to

distinguish between the control and spec treatment groups. The X, Y
data will then be processed through one of the following two algorithms.

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COMPUTER ALGORITHM FOR MANN-WHITNEY TEST

The Mann-Whitney statistic, U, is defined as the total of the number of Y's preceding the 1st X plus the number of Y's preceding the 2nd X, etc., in the combined ordered sample of n X's and m Y's.

The Wilcoxon statistic, T, is defined as the total of the ranks of the Y's in the combined ordered sample and is related to U by

$$U = mn + \left[\frac{m\,(m+1)}{2} \right] - T$$

To calculate T (and hence U) on a computer the procedure is as follows:

1. An indicator (say 0, 1) is associated with each data point indicating to which of the two samples it belongs.

2. The two samples are combined into one ordered sample.

3. T is initialized to zero, and starting with the smallest observation each observation is examined to ascertain if it is a Y or X. If the jth observation (counting from smallest) is a Y, T is increased by j, otherwise not. Thus, after the m+n items in the combined sample have been tested, T has the value of the Wilcoxon rank sum statistic.

COMPUTER ALGORITHM FOR KOLMOGOROV-SMIRNOV TEST

The statistic to be computed from the data is

$$d = \max_{X} \left[S_1(X) - S_2(X) \right]$$

where $S_1(X)$ and $S_2(X)$ are the empirical distribution functions for groups 1 and 2 respectively. The empirical distribution function of a sample is defined as

$$S(X) = 0 \text{ for } X < X_1$$

$$= \frac{K}{n} \text{ for } X_K \leq X < X_K + 1$$

$$= 1 \text{ for } X \geq X_n$$

where $X_1 \leq X_2 < X_3 \ldots \geq X_n$ is the ordered sample point set.

The manual procedure consists of plotting the two empirical distributions on a common graph and ascertaining the maximum difference by inspection. For computer analysis, a computational algorithm is needed. To this end, let X_i, Y_i, (i = 1, 2, ..., n) be the two ordered samples. The maximum difference between the two empirical distributions must occur at some sample point, either an "X" or a "Y". Thus, let Z_i (i = 1, 2, ..., 2n) be the combined ordered sample. The maximum difference must occur at one of the 2n points, Z_i.

$$S_1(Z) - S_2(Z) = \frac{\psi_X}{n} - \frac{\psi_Y}{n} = \frac{\psi_X - \psi_Y}{n}$$

where ψ_X = no. of X's less than or equal to Z

ψ_Y = no. of Y's less than or equal to Z.

Thus, the difference between the two empirical distribution functions at each point, Z, is essentially given by

$$\delta_Z = \psi_X - \psi_Y$$

Recursively,

$$\delta_Z = \delta_{Z-1} + 1 \text{ if Z is an X}$$

$$= \delta_{Z-1} - 1 \text{ if Z is a Y}$$

$$= 0 \qquad \text{if Z is both (a tie)}$$

$$\delta_Z = 0 \text{ for } Z < Z_1$$

Thus the computer algorithm is as follows:

Initially set MAX = 0

$$\delta = 0$$

Working sequentially from "left" to "right" each point of Z_i is examined to determine if it is an X or Y. If an X, $\delta + 1 \rightarrow \delta$. If a Y, $\delta - 1 \rightarrow \delta$.   is now compared to MAX.

If $\delta >$ MAX, $\delta \rightarrow$ MAX, otherwise not.

After the 2n points of Z have been examined, MAX contains the maximum difference.

The final computer output will show all treatment comparisons as a function of part type, parameter and time code differential. The critical values of the "U" or "d" statistic will be read into the computer for the appropriate sample sizes such that rejected hypothesis will be "flagged" by a particular notation on the computer output program. There will be no manual manipulation of data.

    c. Interpretation of Results

        If no significance is found by the computer on any of the comparisons, the hypothesis that there is no difference in the treatment groups is accepted. If, however, there exists comparisons which give statistical significance, then further investigations are in order. It is assumed that any significance will show the spec group as being worse than the control group (the opposite is possible, of course). A thorough "degradation mode" analysis would be recommended on a number of units from the spec groups and these results correlated with similar exercises of the pilot study to ascertain the degree of similarity of degradation. This will be an engineering correlation, not based on rigorous statistical methods. Also, if significance is found, the data of the treatment groups that are independent of the tests of significance will be treated in a statistical manner (no significance tests) such that the sensitivity of the degradation can be determined. This would be accomplished by comparing the pressure group with the spec group for the effects of ultra high stress and then comparing the control group with the spec group (low stress, 25 units) for the effects of ultra low stress.

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STUDY OF ETHYLENE OXIDE EFFECTS

ON COMPONENTS

PART III. ENVIRONMENTAL RESEARCH SATELLITES

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Contract No. 951439

California Institute of Technology
Jet Propulsion Laboratory
Pasadena, California

Subcontract under NASA Contract NAS7-100
Task Order RD-4

TRW SYSTEMS
TRW INC.
One Space Park . Redondo Beach, California

FOREWORD

As an additional measure to establish complete con-
fidence in the ability of component parts to withstand
exposure to sterilization procedures and subsequently
survive space environment, the possible use of an Environ-
mental Research Satellite for extended life testing of parts
is suggested. This might be accomplished as Phase IV
of the Sterilization Test Program.

Cost effectiveness studies indicate that this type of
testing with full instrumentation in actual space orbit is
more economical than long-term testing under conditions
which merely simulate the space environment. Environ-
mental Research Satellites, as described here, are now
available in several designs, weighing from 1.5 to 9
pounds, for piggyback launching from large primary
mission vehicles. Several are presently in orbit.

For a program effort as extensive and significant as
the Voyager, use of such an Environmental Research
Satellite for testing can dispel all remaining doubt re-
garding the effects of ethylene oxide sterilization on the
performance of electronic equipment in space.

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PART III. ENVIRONMENTAL RESEARCH SATELLITES

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I.   INTRODUCTION

A series of small, low-cost, versatile spacecraft called Environmental
Research Satellites (ERS) have been developed by TRW. These spacecraft are
small enough to obtain "piggyback" launches on many of the major launches
customized for one experiment, or one class of experiments, in order to
minimize integration time and compromises of the experimental goals. They
have been flown on several different programs by TRW since 1962 and are
proven vehicles. One recent ERS launch was that of an ORS-III carrying
several nuclear detectors for electron, proton, and gamma-ray measurements
under contract AF 04(695)-703. On 20 July 1965 it was placed into a highly
elliptical (200 n.mi. perigee and 65,000 n.mi. apogee) orbit by the Atlas-
Agena, which had as its primary mission the orbiting of the TRW nuclear
detection satellites (Vela Program).

II.   BRIEF HISTORY

The concept of performing scientific and engineering space research
with small satellites was explored and developed at TRW Systems primarily
because of the difficulties involved in getting on board large scientific
spacecraft. Large spacecraft offer a wealth of vehicle capability which is
necessary for the performance of many scientific missions in space, but
have attendant integration problems and long development times and are
necessarily expensive. Some space research and testing can be conducted
with less complex spacecraft at a consequent savings of money and develop-
ment time. There are also some missions which can be better performed on a
small spacecraft which may not require the compromises involved in a larger
multisystem satellite.

In the fall of 1960, work was begun towards development of a small,
lightweight satellite that could be orbited as a secondary payload with a
main spacecraft or could be orbited as a primary payload with small booster
systems. The objective of this spacecraft design was to obtain a
completely independent satellite system which was simple and reliable, and
to   impose no significant burden on any other booster or main spacecraft
systems. The result of this system's approach was a group of environmental

research satellites which are identified by their regular polyhedral shape,
namely, tetrahedrons and octahedrons. The initial program was directed
toward a small tetrahedron which carried solar cells for measurement of
damage produced by the energetic trapped electrons produced by high-altitude
nuclear-bomb testing. These small satellites were launched in pairs from
the second stage of a main spacecraft system. The success of this program
led to subsequent programs utilizing more sophisticated subsystems to
support the new experiments, and gradually to a spacecraft family with
quite versatile subsystem capabilities. A description of prior and current
ERS programs is given in Section V of this brochure. As an indication of
the fast response capabilities of these small satellites, the first flight
occurred just four months after an Air Force directive for radiation measure-
ments following the Project Starfish Johnston Island nuclear detonation.

III.   APPLICATIONS FOR ERS

        The Environmental Research Satellites can be utilized for any unmanned
spacecraft applications. Table I lists Environmental Research Satellites
under firm contract. As of 9 January 1966 there are twenty-seven in all. It
includes past missions that have already been orbited and missions currently
in development. Detailed discussions of these missions are included in a
later section of this brochure.

        Immediately following is a list of some other missions that have
received significant engineering planning for ERS application:

          1. Communication
          2. Range Calibration - S-band and C-band
          3. Zero-Gravity Dielectrophoresis Heat Transfer
                Experiment
          4. Synchronous Gravity Gradient System Evaluation
          5. Earth Orbiting Circadian Rhythm Study using
                Perognathus Longimembris Mice
          6. Zero Gravity Oxygen Chamber Combustion
                Experiment
          7. Free Molecule Measurements

8. Plasma Sheath and Electric Field Measurements

9. Sterilization of Spacecraft Components

10. Ultraviolet Albedo Measurements

11. Component Testing

    a. Small Thrusters and Special Catalysts

    b. Batteries

    c. Electromechanical Drive System

Table I
ENVIRONMENTAL RESEARCH SATELLITE PROGRAMS

ERS Serial Number	Model Number	Experiment	Experimenter	Contractor	Launch Date	International Designation	Transmitting Frequency
1	TRS-I	Solar Cell, Radiation Damage	Denney Downing	AFSSD			108.06
2	TRS-I	"	Denney Downing	AFSSD	9-19-62	Alpha Chi-II	108.06
3	TRS-I	"	Denney Downing	AFSSD	12-17-62		108.06
4	TRS-I	"	Denney Downing	AFSSD	12-17-62		108.09
5	TRS-I	"	Denney Downing	AFSSD	5-9-63	1963-14B	136.41
6	TRS-I	"	Denney Downing	AFSSD	5-9-63	1963-14C	136.89
7	TRS-I	"	Denney Downing	AFSSD	6-12-63		136.89
8	TRS-I	"	Denney Downing	AFSSD	6-12-63		136.41
9	TRS-I	"	Denney Downing	AFSSD	7-19-63	1963-30B	136.89
10	TRS-I	"	Denney Downing	AFSSD	7-19-63		136.41
11	TRS-II	2 Charged Particle Radiation Detectors	Denney Vette	AFSSD			136.02
12	TRS-II	"	Denney Vette	AFSSD	10-16-63	1963-39B	136.53
13	TRS-II	"	Denney Vette	AFSSD	7-17-64	1964-40C	136.77
14	TRS-II	2 Charged Particle Radiation Detectors	Walker	AFSSD			136.03
15	ORS-II	Coldwelding	Hammel	AFRPL			136.440
16	ORS-II	Coldwelding	Hammel	AFRPL			136.440
17	ORS-III	5 Nuclear Radiation Detectors	Denney Vette	AFSSD	7-20-65	1965-58C	136.770
18	ORS-III	"	Denney Vette	AFSSD			136.530
19	ORS-III	Friction	Hammel	AFRPL			Xmtr - Comm -
20	ORS-III	Friction	Hammel	AFRPL			Xmtr - Comm -
21	ORS-III	Zero g Heat Transfer.	Robinson	AFRPL			Xmtr - Comm -
22	ORS-III	"	Robinson	AFRPL			
23	ORS-II	Classified					
24	ORS-II	Classified					
25	ORS-II	Classified					
26	ORS-III			AFSSD (AFCRL)			
27	ORS-III			AFSSD (AFCRL)			

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IV.   SPACECRAFT DESCRIPTION

TRW Environmental Research Satellites include octahedral and tetrahedral and other shaped satellites with edge lengths generally ranging from 6 inches to 15 inches. The octahedron and tetrahedron were originally selected in the ERS programs because these shapes were well suited to solar cell power supply applications, in that they provide lesser variation in projected area and thus more nearly constant output. These shapes, particularly the octahedron, have proven to be desirable from such viewpoints as satellite dynamics, fabrication, testing accessibility, and stowage on the launch vehicle. Other structures, in particular, octahedral prismatic and cylindrical shapes are now being engineered for future applications.

A versatile and reliable series of subsystem capabilities have been developed. Those subsystems associated with firm contracts or which have received significant engineering planning are listed below. Many other specialized subsystems have been provided for previous missions and others can be provided as required. In the following section are detailed descriptions of some specific subsystems most frequently used on ERS satellites, as well as description of the structure and the ejection and containment system.

1. Stabilization
    a. Passive Magnetic
    b. Magnetic Torquing
    c. Gravity Gradient
2. Electrical Power
    a. Solar Panel System
    b. Supplementary Battery and Charger System
3. Telemetry
4. Command-Receiver
5. Antenna
6. Data Storage
    a. Tape Recorder
    b. Magnetic Core
    c. Latching Relay
7. Thruster System
8. Sun Angle Sensor

Table II provides packaging and weight data for ERS support subsystems. Figure 1 is a photograph of a full-scale model of the ERS Zero-Gravity Liquid-Heat-Transfer Experiment which is to be orbited in the near future. Such models are used as tools in determining final packaging configurations. Other subsystems than those discussed below and other versions of some of these same subsystems are also available.

TABLE II

ERS SUPPORTING SUBSYSTEMS
PACKAGING AND WEIGHT DATA

		Volume (cu.in.)	Weight (lbs)
Electric Power:			
A) 10 Cells each of	1.02" dia. x 1.93"	15.5	1.6#
B) Voltage Regulator	2½" x 1½" x ½"	1.9	0.6
C) Battery Charger	2" x 2" x 1.5"	6.0	0.7
D) Solar Panels - external to spacecraft		--	2.0
E) Wires, Plugs, etc.		--	0.5
		23.4	5.4#
VHF Telemetry:			
F) Transmitter	4.7" x 2" x 1 1/8"	11.7	0.3
G) SCO	3.5" x 2.15" x 3/4"	5.6	0.2
H) Commutator	2.8" x 1.5" x 0.8"	3.4	0.2
		20.7	0.7#
VHF Command-Receiver:			
I) Receiver	4½" x 3½" x 1"	15.8	0.5
J) Decoder	4½" x 3½" x 1¼"	19.7	0.6
K) Logic Unit	4" x 2¼" x 1"	9.0	1.0
L) Diplexer, VHF	2" x 1" x ½"	1.0	0.3
		45.5	2.4#
Stabilization System:			
M) Magnet	1½" x 1½" x 1"	2.2	0.1
N) Magnetic Damper	11" x 11" x ¼"	30.2	0.1
		32.4	0.2#
Other:			
O) Ejection System - external to spacecraft		--	--
P) Structure		--	1.7
			1.7#
	TOTALS	122.3 cu.in.	10.4#
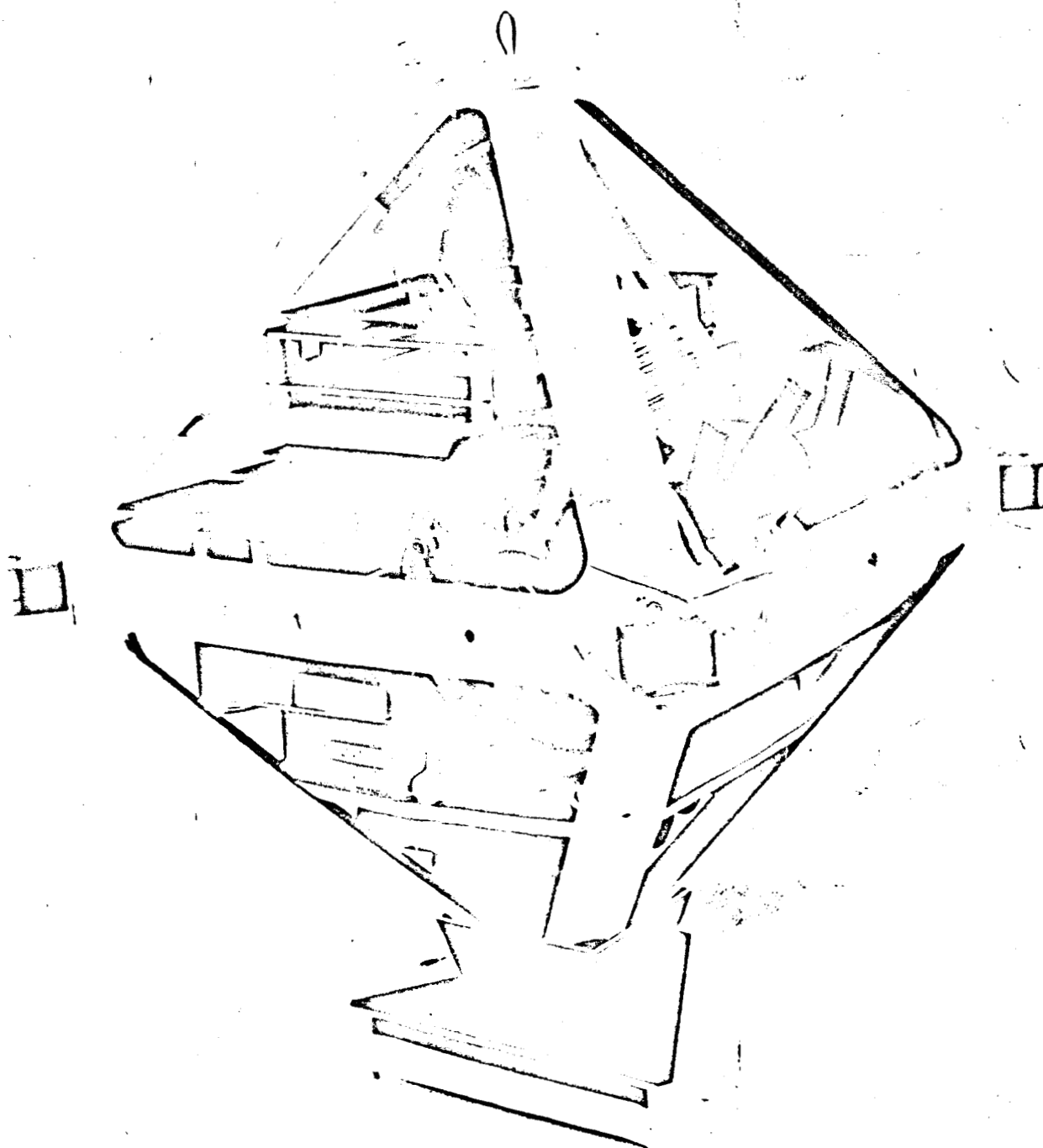
Figure 1.   Photograph of Full Scale Model for
ERS Zero-Gravity Liquid Heat Transfer Experiment

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IV-A.   STRUCTURE

The first launches of ERS satellites employed tetrahedra; later
octahedral shapes were more frequently used. More recently we have been
developing satellites of other shapes for different missions.   The
selection of a particular shape is dependent upon the requirement of the
particular mission involved. The polyhedral shapes were used initially
because of electrical power system considerations, in that they permitted
further simplification for very simple missions. One of the other ERS
shapes is prismatic.   A photograph of a full scale mock-up of a
prismatic ERS which was developed for an earlier program is included as
Figure 2. Some description of the octahedral structure which was the
most recently orbited ERS satellite is included as follows:

The octahedral structure is an all-aluminum framework, which
provides the mounting supports for both external and internal components.
The frame consists of 12 formed members which constitute the edges of the
octahedron. Shear webs support the exterior framework and provide plat-
forms for mounting components. The entire system of external and
internal members is integrally brazed to form a rigid structure; however,
the frame is separable   in order to provide access during installation
of larger components. A fitting at one apex serves as a support during
launch and as a guide during separation from the launch vehicle. Trianuglar
solar cell panels are mechanically fastened to the framework and can be
easily removed for access to electronic circuitry. The only other external
parts on the most recently orbited vehicle were the antennas and a fitting
at the bottom apex for retaining the spacecraft in its container. Other
appendages such as special antennas and gravity gradient booms are attached
for other missions, as required. A photograph of this ORS-III with solar
panels removed is included as Figure 3. This ORS-III was launches on
20 July 1965.
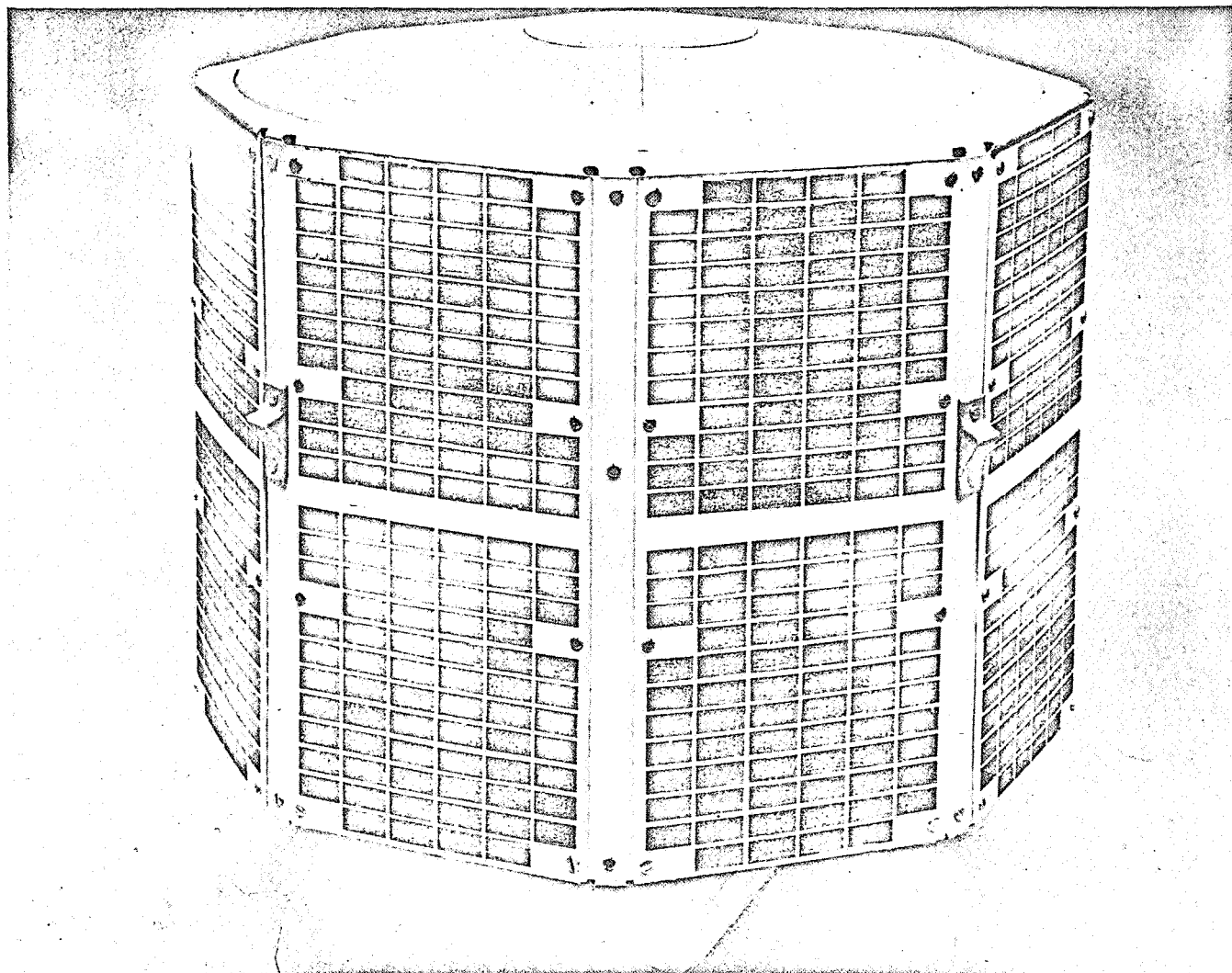
Figure 2. Photograph of Mock-up of Prismatic ERS
Developed for an Earlier Program.
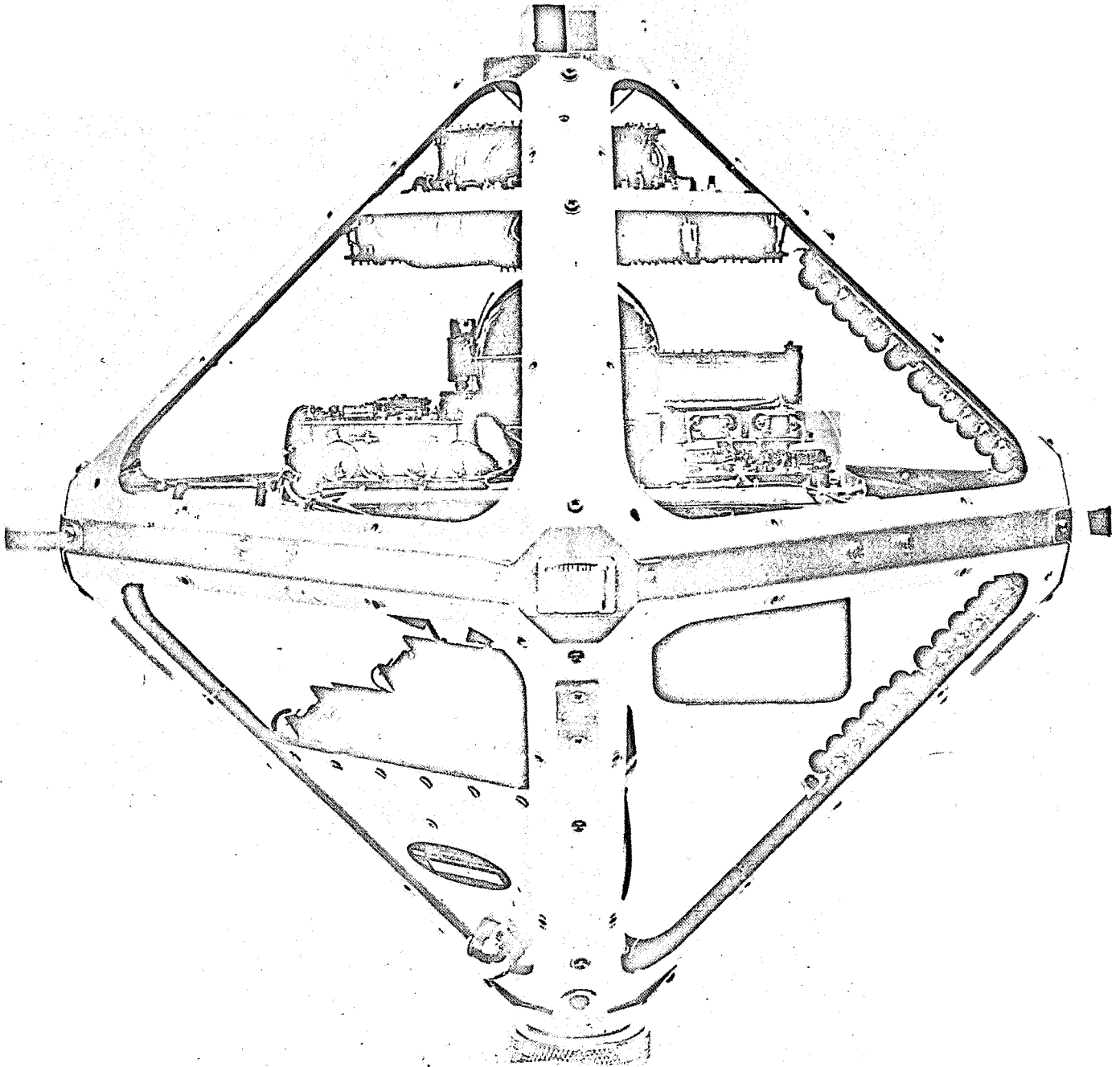
Figure 3. Photograph of ORS-III Flight Structure
(Most Recent Flight)

IV-B.   EJECTION AND CONTAINMENT SYSTEM

At launch, these small spacecraft are mounted in containers which provide support and also incorporate the ejection mechanisms. For most launches the container has a center support post and additional load support points. For the octahedrons, the load support points are located at the plane of the four apexes. A pyrotechnic pin puller retains the spacecraft in the container, and, on firing, the separation is initiated. The spacecraft is ejected by spring actuation which results in a separation velocity of approximately three feet per second from the boost vehicle. The VHF antennas are stowed in coils during launch and maintained in position by retainers on the container. As the satellite is ejected, the antennas are released and immediately deploy into straight dipole positions.

In most cases a system of cams is employed to impart a slow spin (eg. 10 rpm) to the satellite, in order to facilitate later thermal control of and communication with the satellite, and for better solar cell performance. In some cases a higher spin rate is imparted and in others no intentional spin, depending on the requirements of the particular mission. With no intentional spin, an extremely low acceleration environment on the order of 10^{-4} to 10^{-5} g's can be obtained. Even lower accelerations can be obtained with the addition of a magnetic damping matrix.

The spacecraft container is the only interfacing item with the booster vehicle. The spacecraft interface consists of only four machine bolt fasteners and a single 22V electrical connection for the pyrotechnic pin puller. A photograph of an ORS-III in its container is included as Figure 4.
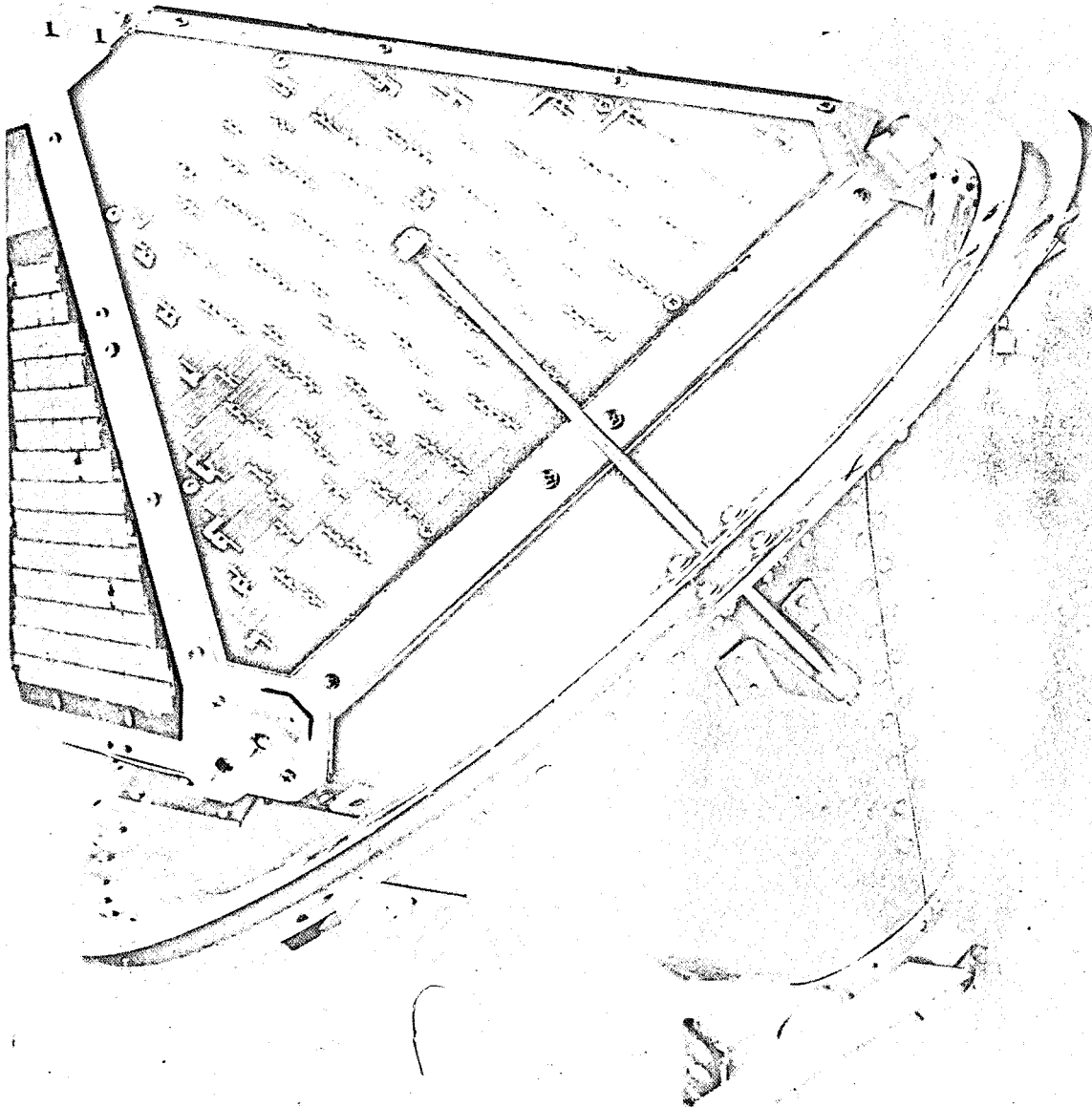
Figure 4.   Photograph of ORS-III with
Containment and Ejection System

IV-C.   SPACECRAFT ORIENTATION

A number of types of spacecraft orientation systems are available
with ERS satellites for missions that might require this feature. Three
types of subsystems that are well suited for ERS application are:

1. Spin
2. Passive magnetic
3. Active magnetic with provisions for torquing
4. Gravity gradient systems

Each of the foregoing orientation systems is valuable for a particu-
lar type of spacecraft orientation control. These systems are frequently
used in conjunction with a sun-aspect sensor system which provides positive
orientation data. The spin technique is sufficiently simple and straight-
forward, such that it will not be discussed here.   A   discussion of the
different capabilities of the other three systems listed above is provided
below. Also some detailed description of two of these systems is provided.

Passive Magnetic: Next to the spin system, the passive magnetic
system is the simplest and possibly the least expensive. It has received
significant engineering design attention for these small ERS satellites
and provides attitude control in the order of 10° accuracy along the direction
of the Earth's magnetic flux. This type of system has been used in orbital
space flight as far back as 1961 (Transit) and has proven successful in
providing proper orientation within 6 to 20 hours after launch. As an
example of usage, this system is suited for aligning spacecraft antennas
for optimum linkage with ground stations. It can also permit various types
of aiming of such devices as infrared detectors. For example, by placing
the satellite into an equatorial orbit, the IR detector can be aimed with a
10° accuracy into the northern or southern galactic sphere; or by placing
the satellite into a polar orbit, the IR detector can be made to scan 360°
twice each orbit of the satellite. The scan direction would be along the
direction of the Earth's magnetic lines of flux. In this case, the satellite
inverts each time it crosses the Earth's poles.

Active Magnetic: Active magnetic stabilization employs a spinning satellite and provides electromagnet torquing capabilities. The spinning vehicle remains oriented in inertial space unless the electromagnet is activated via a command from a ground station, and at that time the spinning satellite is torqued, or precessed, in a direction dependent on the direction of the local Earth magnetic field. Selection of the time for ground command is based upon satellite ephemeris data and aspect data. Subsequent corrections are made until the vehicle is "jockeyed" into the desired inertial orientation. With this system, a relatively accurate pointing can be made to almost any place in the universe. This system would permit such functions as aiming an infrared sensor at a sector within the Milky Way during an IR astronomy mission. This particular orientation system is particularly attractive because of its versatility and accuracy.

Gravity Gradient: Still another type of orientation can be obtained with a gravity gradient system. Such a system is capable of maintaining one axis of the satellite pointing towards the Earth, or conversely, one axis pointing away from the Earth at all times. Pointing accuracies of 1 to 5° can be obtained, depending on the degree of refinement built into the system. In the case of an infrared astronomy mission, the gravity gradient system would permit the scanning of gradually changing discs of the universe for infrared energy. For a communication mission, it would permit use of a higher-gain antenna, because it always points one axis towards the Earth's surface. Other applications might be observational missions, such as for weather, video, or UV Albedo.

Combinations of these systems can also be provided. For instance, it is possible to provide the orientation of a passive magnetic system for a period of time, and later, that of a gravity gradient system.

Description of Passive Magnetic Orientation Control System

This magnetic stabilization system consists of two basic functional elements. One is a magnet which will provide the driving force for aligning the spacecraft in the desired magnetic orientation. The other is a permeable-rod damping matrix which will damp out any initial satellite spin and also damp out oscillation or precessions and nutations about the desired orientation axis by dissipating the energy of these motions. A satellite with the magnet has a large magnetic dipole moment and will, like a simple compass, tend to align itself along the direction of the Earth's magnetic field. In the absence of damping, the magnetic torque will cause the satellite to oscillate about the local direction of the magnetic field in a manner similar to that of a simple pendulum. The permeable-rods serve to damp the satellite motion by providing a hysteresis loss during each cycle of oscillation.

Physically, these elements are a permanent bar magnet with a magnetic moment of 75 dyne-cm/gauss and 16 permeable-rods arranged in a grid layer and mounted in the equatorial plane of the satellite (see Figure 5). The rods are made of a nickel-iron alloy (47.5% nickel and 52.5% iron) called AEM 4750. The selection of this material was based on its superior energy-dissipation ability. Approximate weights for the stabilization system are 0.11 pounds for the permanent magnet and 0.09 pounds for the 16 damping rods, or a total of 0.20 pounds.

This magnetic stabilization system controls attitude to approximately 10°. The total time for magnetic stabilization includes the acquisition time and the time required for damping the initial tumble rates at injection. The roll axis of the satellite may be expected to acquire the direction of the Earth's magnetic field (within ± 10°) usually within three to ten orbits (orbit period of approximately two hours).

MOUNTING CONFIGURATION
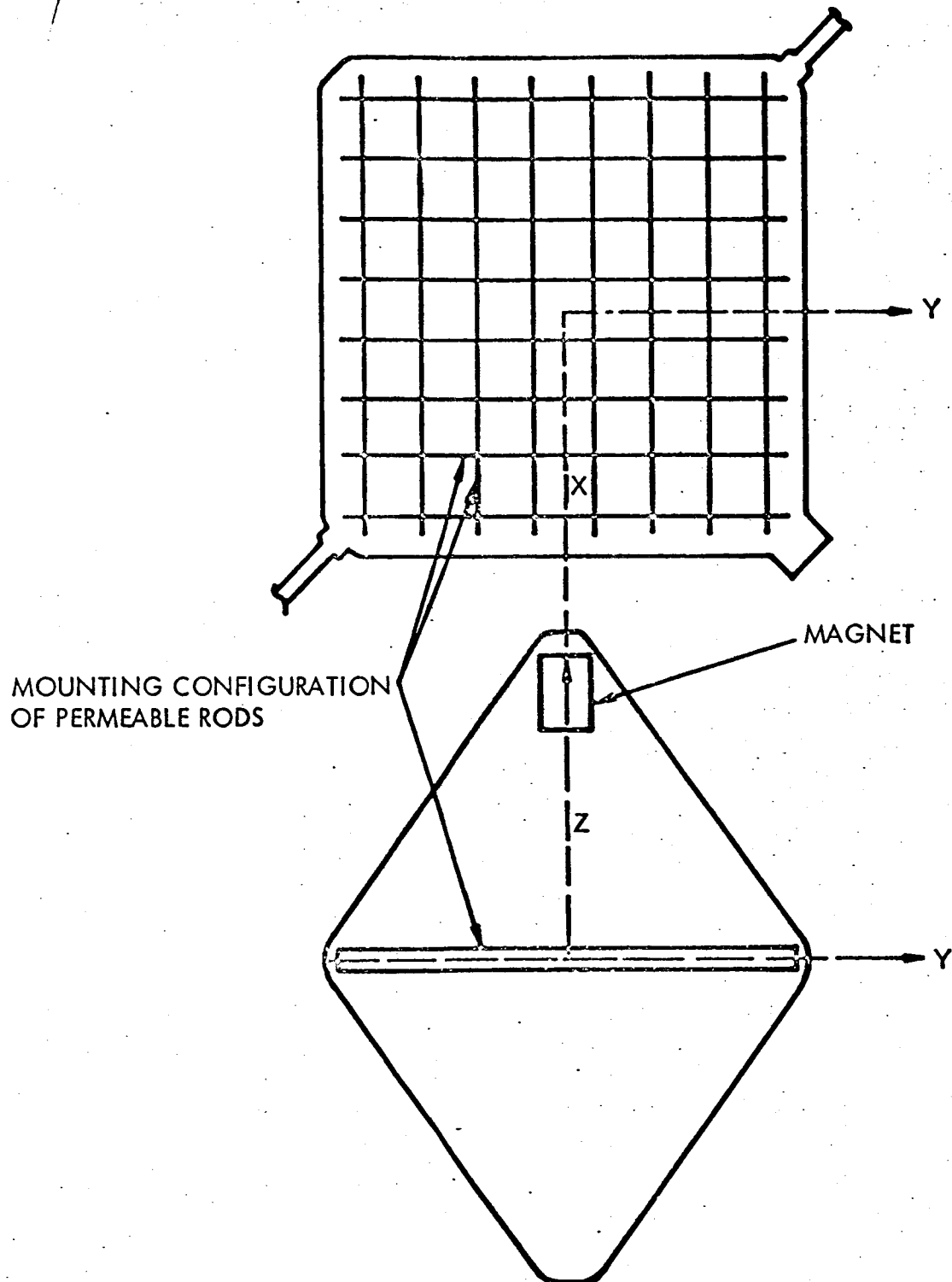OF PERMEABLE RODS

MAGNET

Figure 5

MOUNTING CONFIGURATION OF PASSIVE MAGNETIC
STABILIZATION SYSTEM COMPONENTS IN AN ORS

Description of Gravity Gradient Stabilization Systems

Gravity gradient stabilization systems utilize the differential gravity field of the Earth to produce an alignment torque on the satellite. If a long boom is erected from a spacecraft in order to increase its moment of inertia, this boom will tend to align along a local vertical. A damping system must be added to the spacecraft to remove the oscillation energy of this boom around the local vertical. Quite a few gravity gradient systems have been proposed, differing only in the type of damper utilized. Since 1962 several gravity gradient systems have been successfully flown.

Two different kinds of gravity gradient systems have been designed for the ERS spacecraft. For low altitude missions where an alignment of only 10° to the local vertical is required, an extremely simple system with no moving parts is offered. This system utilizes one rigid boom of about 50-foot length and a damper made up of permeable magnetic rods located in the spacecraft. These rods lose energy as they oscillate in the Earth's magnetic field, which is relatively strong at low altitudes. The rods have a lossy hysteresis loop and dissipate the energy of oscillation.

For gravity gradient systems that would align to 1° at low altitudes and for utilization of altitudes of synchronous orbits, the standard TRW quartz-fiber hysteresis-damper system is utilized with a multi-boom array.

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ELECTRICAL POWER SUPPLY

The electrical power supply is based on the use of solar panels, frequently supplemented by batteries. Use of batteries permits short-duration, high-power-level operations and operation during eclipse.

To illustrate typical power levels attainable with just the solar cell supply, the most recent ERS launch will be used as an example. This satellite is currently in orbit and employs an 11" edge-length octahedron. Its solar panel electrical power supply is producing a maximum of 5 watts and an average of 3.9 watts. This basic solar cell power supply makes use of all of the satellite's faces (eight for the octahedron), each of which supports a matrix of 1 cm x 2 cm solar cells with protective thermal covers. There are 102 cells per face which are electrically arranged into three paralleled, series strings of 34 cells. The eight faces are connected in parallel through the use of blocking diodes which limit loss in non-illuminated faces. Twenty-mil quartz covers with 400 micron cutoff filters on the solar cells are used for that particular mission for spacecraft temperature control and also for charged-particle radiation protection. Individual cells are soldered to insulated, evaporated-copper contacts in bonded, impregnated glass cloth. The resulting panels have been tested for thermal cycling, vibration, and shock far in excess of any flight requirements. The covers are bonded to each solar cell individually.

Batteries are frequently used to supplement the basic solar cell supply, and this combined configuration permits limited duration, high-power-level operations and operation during eclipse. This combination is being used on many other ERS missions. To illustrate the capabilities of supplemental battery systems available with this spacecraft, a typical ERS system design on board a fifteen-inch ORS will now be described. Requirements for this typical mission are 15 watts continous during the maximum power mode and only 0.1 watts in the minimum-power (or standby) mode. These requirements exist during both sunlight hours and eclipse. (One ERS mission currently being prepared for orbital flight includes a 30 watt mode). The power supply consists of the ERS solar panels and voltage regulator and is augmented by a rechargeable battery system (illustrated in Figure 6). The
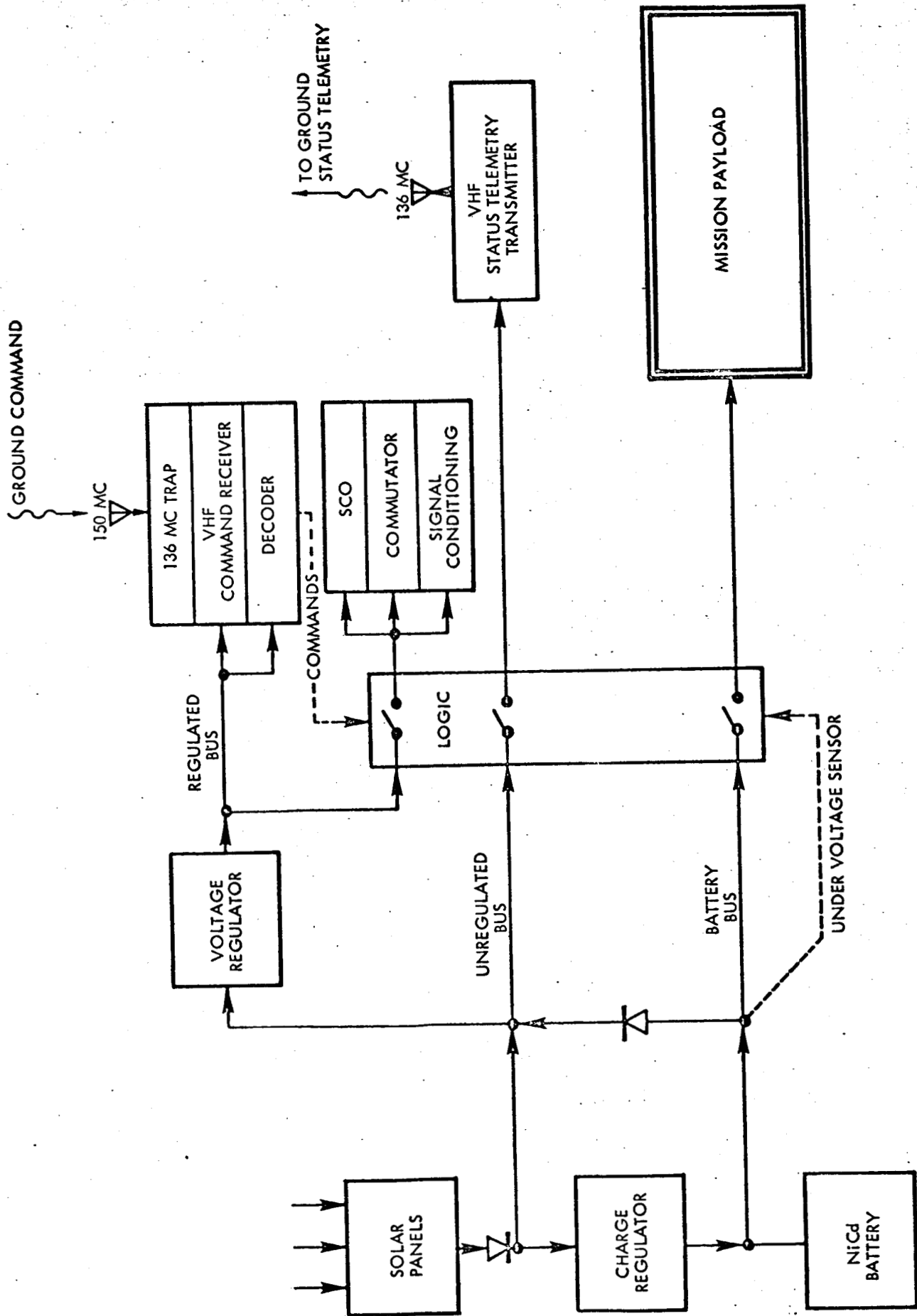
Figure 6

ELECTRICAL POWER DISTRUBUTION BLOCK DIAGRAM

solar panels and voltage regulator are identical to those used in previous flights, and the batteries are one size from a series of available off-the-shelf NiCd batteries. The battery system supplies power during eclipse time operation and during payload transmit intervals. Calculations of maximum continuous operating time and duty cycle are included below. In order to simplify these calculations, certain approximations have been employed, such as averaging the effects of eclipse time:

1) Maximum battery system capacity   =   48 Watt Hours

2) Energy available at 70% usage   = 33.6 WH

3) Maximum power required (selected for illustration purposes)   =   15 Watts

4) Average power from solar panels   = 7.2 W

5) Battery drain during sunlit hours   = 15 - 7.2 = 7.8 W

6) Battery drain during eclipse hours   = 15 W

7) Percent time in sun (for nominal equatorial orbit) $\approx$ 75%

8) Maximum continuous operation   =

$$\frac{33.6}{(.25)(15) + (.75)(7.8)} = \underline{3.5 \text{ Hours}}$$

9) Minimum orbital power required (command-receiver on)   = 0.14 W

10) Battery charge efficiency   = 75%

11) Sunlit battery charge power   = 7.06 W

12) Eclipse battery drain rate   = 0.14 W

13) Recharge time after 70% discharge   =

$$\frac{33.6}{(.75)(.75)(7.06) - (.25)(0.14)} = 8.5 \text{ Hours}$$

14) <u>Duty cycle</u> $= \dfrac{3.5}{3.5 + 8.5} = $ <u>0.29</u>

Figure 7 shows allowable duty cycles for ERS 6 inch, 9 inch, 11 inch, and 15 inch octahedrons for various payload power levels. For ERS satellites of different shapes these curves can still be used by selecting the curve for the ORS with approximately equal projected area.

The battery system for the foregoing illustrative example consists of 10 NiCd battery cells and a charge regulator. This regulator controls the flow of current from the solar cell panels to the battery and prevents a damaging overcharge condition while still permitting maximum utilization of the available power. An undervoltage control is also included, which will generate an internal OFF command in the event that the battery approaches the discharge limit, and thereby prevent battery system damage. Average capacity for the 10 cell battery system is 48 watt hours. The physical dimensions of each cell are 1.3 inch diameter by 2.4 inches high. This series of batteries has been flown in more than 20 spaceflights.
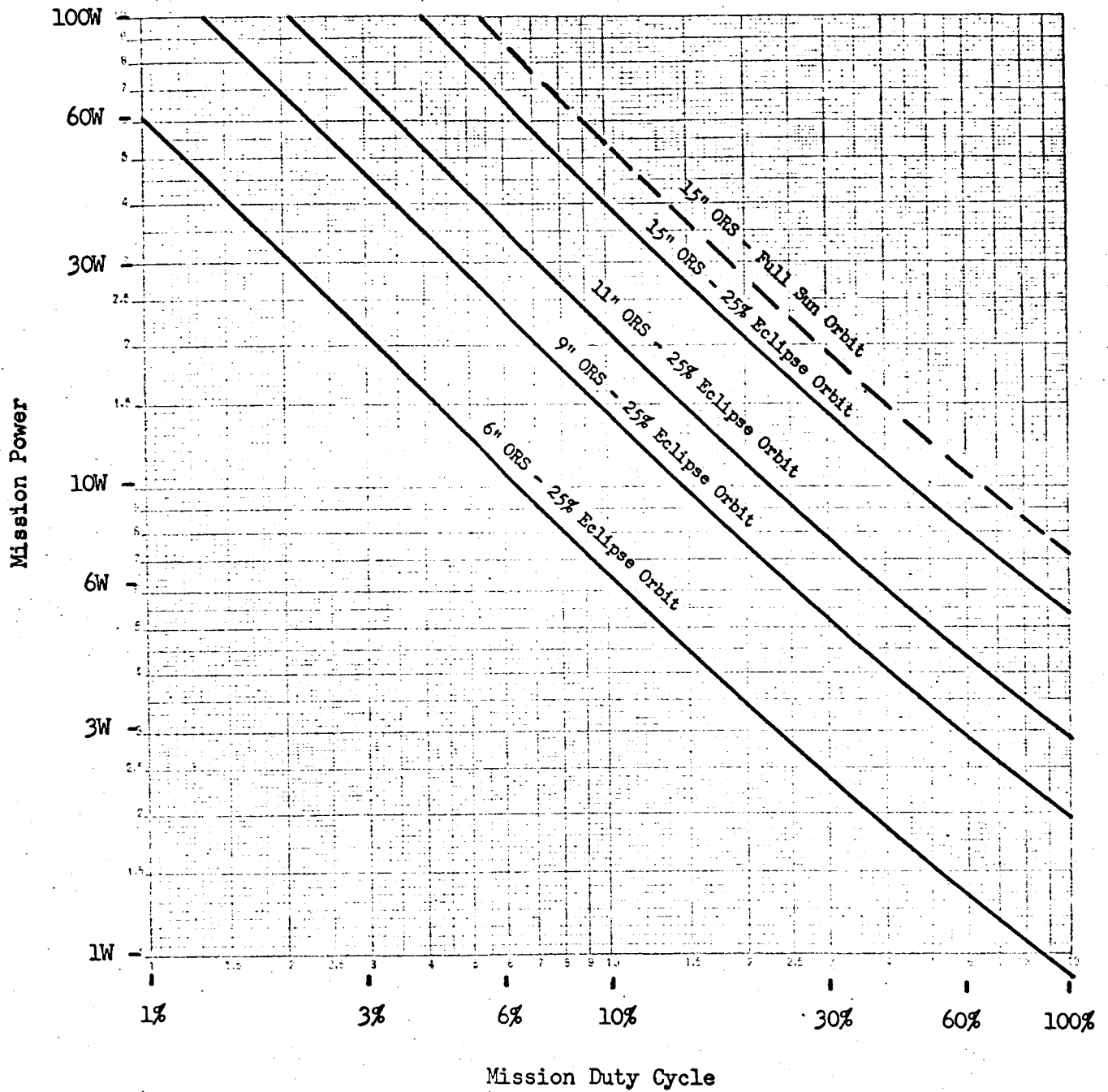
Figure 7. Allowable Duty Cycle for
Battery Supplemented System

IV-E.   TELEMETRY SYSTEM

VHF transmitters have been employed on all past ERS satellite flights
for telemetry, but transmitters for other frequencies can also be supplied.
VHF transmitters are compatible and are normally used with the NASA STADAN
Network. Transmitters of either 100 milliwatts and 1 watt have been used on
past flights with the selection depending upon mission requirements. Other
R.F. power levels can also be provided. A 25 watt transmitter is currently
being considered for a specific mission.

The transmitters used to date are PAM/FM/PM systems with a carrier
frequency of 136 mc. A subcarrier oscillator designed to operate on IRIG 5
subcarrier band (1300 cps $\pm$ 7$\frac{1}{2}$%) is normally used. However, other IRIG
channels with wider bandwidths or other modulation methods can be used. For
example, IRIG channel E with an intelligence bandwidth of 2,000 cps has also
been sized for ERS use. The commutator/subcommutator is employed for gating
the various data channels and is sequenced by a standard timer. Analog
telemetry is transmitted at a range-tested accuracy of about 1 per cent.
The components making up the complete transmitter subsystem are the electronic
commutator, subcarrier oscillator, transmitter, and dipole antenna. In order
to be compatible with range requirements, an end-of-life timer is included
to shut off the transmitter permanently at a preselected time. Telemetry
reception and data acquisition are normally performed by the NASA STADAN
Network. Analog data format is employed, and it is recorded on Sanborn
recording paper and on magnetic tape. Data is normally transmitted sequentially.
For a typical mission, each data point would be sampled for three seconds, and
there would be 32 commutated data points. The telemetry power budget included
below shows that telemetry reception from at least 20,000 nautical miles can
be accomplished with standard Minitrack 30-foot dish antennas and the 100 mw
transmitter for IRIG 5, and this capability has been verified in actual flight.
In fact, telemetry data reception of this 100 mw transmitter has been success-
fully accomplished with a STADAN 85-foot dish antenna throughout a 108,000
kilometer apogee. The budget shows the range for reliable reception from the
1 watt transmitter with a 30-foot dish to be 63,000 nautical miles and this has
also been confirmed in actual flight. Use of other IRIG subchannels or other
modulation schemes would change the maximum range.

VHF R.F. POWER BUDGET — DOWNLINK

Status Telemetry Power 100 mw	+ 20 dbm
Spacecraft Antenna Gain	0 db
Polarization Loss	− 3 db
Ground Antenna Gain (30-ft. dish)	+ 19 db
Cable and Miscellaneous Losses	− 3 db
TOTAL	**+ 33 dbm**

Ground Receiver Sensitivity (for IRIG 5)	− 140 dbm
Available for Space Loss	173 db
Margin for Reliable Operation	6 db

MAXIMUM RANGE WITH 6 db MARGIN
FOR 100 mw SYSTEM   20,000 n.mi.

MAXIMUM RANGE WITH 6 db MARGIN
FOR 1 watt SYSTEM   63,000 n.mi.

IV-F.   COMMAND-RECEIVER

A standard VHF command-receiver system is readily available for
missions requiring function control. This receiver is being used on a number
of other ERS programs and is a comerically available, fixed-tuned, VHF, AM
receiver designed for satellite use and is flight qualified. Its light weight,
small size and low power consumption make it ideally suited for use in
Environmental Research Satellites. It is a single-conversion receiver utilizing
silicon transistors in a configuration which features a unique departure from
conventional minature VHF receiver designs. One 18.1 mc crystal filter in
conjunction with low level demodulation and high gain audio amplification is
used to give outstanding savings in size, weight, reliability, and power
consumption. Dynamic range is 80 db nominal. Bandwidth is 10 kc, which is
adequate for worst-case doppler. Only 137 mw of power is required for
continuous standby operation from the unregulated solar panel output. It
measures 3.5 x 4.5 x 1 inch and weighs less than half a pound.

Uplink R.F. power budgets are shown below which assumes the use of
equipment presently operational at NASA STADAN stations. All of these stations
have 200w transmitters, most have 2.5KW, and some have 5KW. The power budgets
indicate that commands can be received over a maximum of 150,000 n.mi. range
or 75,000 n.mi. if a 6 db margin is allowed to provide assurance of reliable
reception.

<div align="center">VHF R.F. POWER BUDGET -- UPLINK</div>

Ground Transmitter Power (2.5KW)	+ 64 dbm
Ground Antenna Gain	+ 13 db
Cable and Miscellaneous Losses	- 3 db
Receiver Antenna Gain	0 db
Spacecraft Cable & Diplexer Losses	- 1 db
Polarization Loss	- 3 db
TOTAL	+ 70 dbm
Receiver Sensitivity	- 110 dbm
Available for Space Loss	180 db
MAXIMUM RANGE	150,000 n.mi.
Carrier/Noise Margin to Assure Reliable Operation	6 db
MAXIMUM RANGE WITH 6 db C/N	75,000 n.mi.

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The tone decoder is a companion piece to the command receiver and is designed to operate with it. It consists of eight band pass filters: one address tone and seven execute tones. The tone frequencies are those specified in NASA Aerospace Data System Standards X-560-63-2. External circuitry provides the logic required for 21 separate commands which uniquely control a particular satellite by means of a sequence of three tones, one address and two execute. This system is compatible with existing equipment at all STADAN stations. The logic circuitry is separate from the decoder itself to permit greater flexibility in satellite design. Basically, the command logic is arranged such that three sequential tones are required; the address tone first, followed by two execute tones. Each has a half second duration with a half second silent period between. If any one of these requirements is not fulfilled, the system resets and awaits the next command. Random noise is thus prevented from causing spurious commands. The tone decoder is housed in an enclosure which matches the command receiver such that they may be stacked if desired. The decoder measures 3.5 x 4.5 x 1.25 inches and weighs ten ounces.

IV-G.   ANTENNA SYSTEMS

The antenna configuration depends on whether a command-receiver system is included, whether or not the usual VHF frequencies are employed, and on whether a different system is required for the mission. In this latter case, a single monopole receive antenna might be substituted for the usual dipole. Typically the components of the antenna system protrude from four apexes of an octahedral satellite, and these four apexes used are all in one plane. Two opposing antenna components make up the standard dipole used by the VHF transmitter. This transmit dipole would be identical to those used on all previous octahedral satellite flights. The other two apexes in the plane could support a VHF receive system dipole, or a simple monopole could be used. The transmit dipole and a receive monopole will be described in more detail below.

A typical antenna pattern for the VHF transmit dipole for an orientation that is particularly illustrative is included as Figure 8. This pattern was taken on the most recent, production unit, eleven-inch octahedron which is currently in orbit. It may be seen that the coverage provided is of a toroidal shape with low-gain points, or nulls, at two, small sector, opposing points. These dipole elements are fabricated from beryllium-copper tapes which have been formed and heat treated into a convex shape, thus allowing them to be coiled or rolled for compact storage in a manner similar to hardware tape measures. This technique results in an antenna element that is quite rigid in its deployed position and yet can be stored in a small volume with a capability of reliable deployment. The elements are a quarter-wavelength long, tuned internally for 50-ohm impedance match, and then connected to the transmitter output network.

The antenna system for the VHF command link consists of either a dipole or a monopole. A monopole antenna element, in conjunction with the spacecraft body, provides a radiation pattern characteristic of a half-wave dipole in free space. The coverage provided, therefore, is of a toroidal configuration. A full-scale pattern taken by actual test is included as Figure 9. The maximum gain is located approximately at the equatorial plane with a value in the neighborhood of 2 db with respect to a linear isotrope. This monopole element is fabricated in the same manner as those for the transmit antenna.
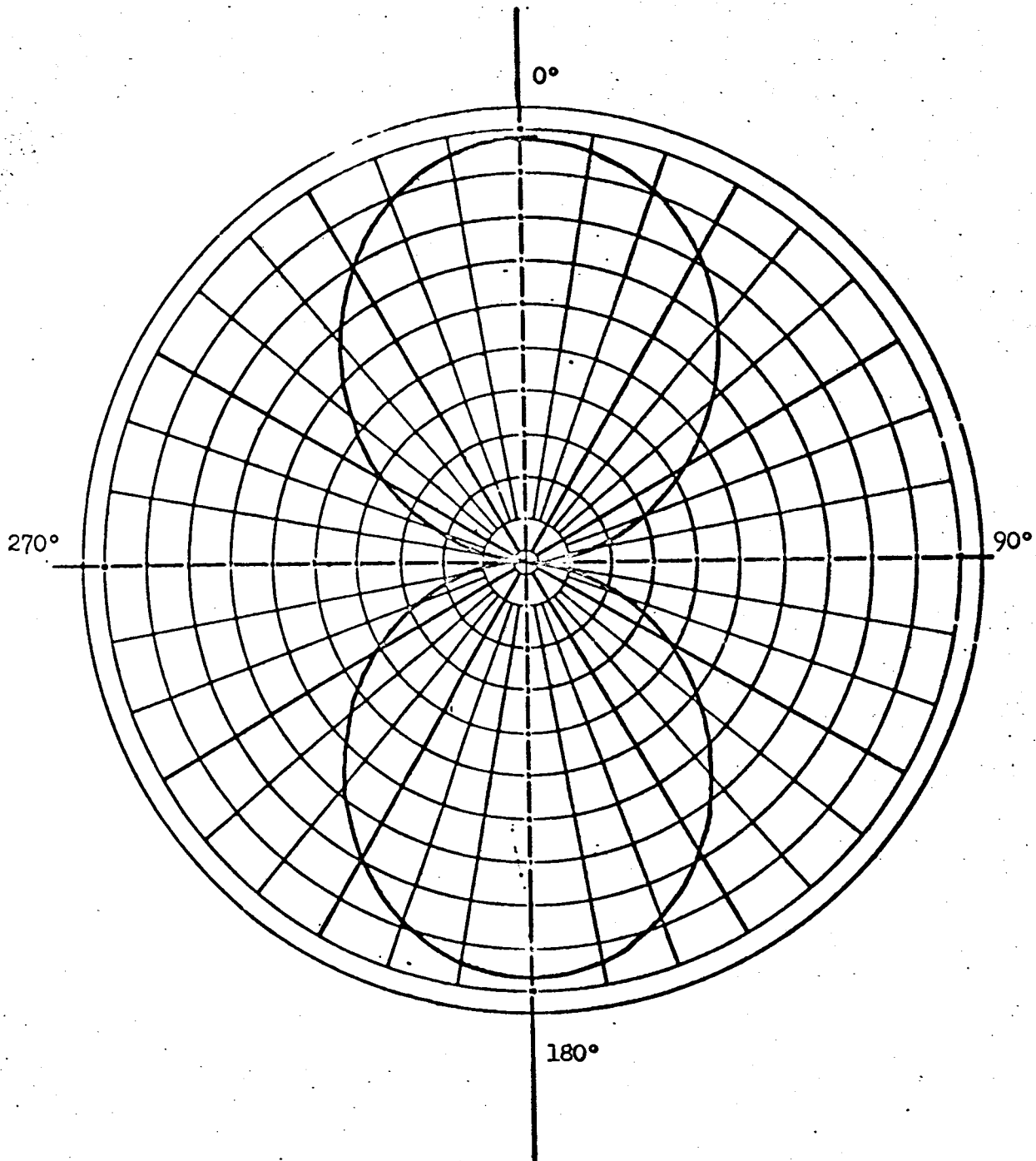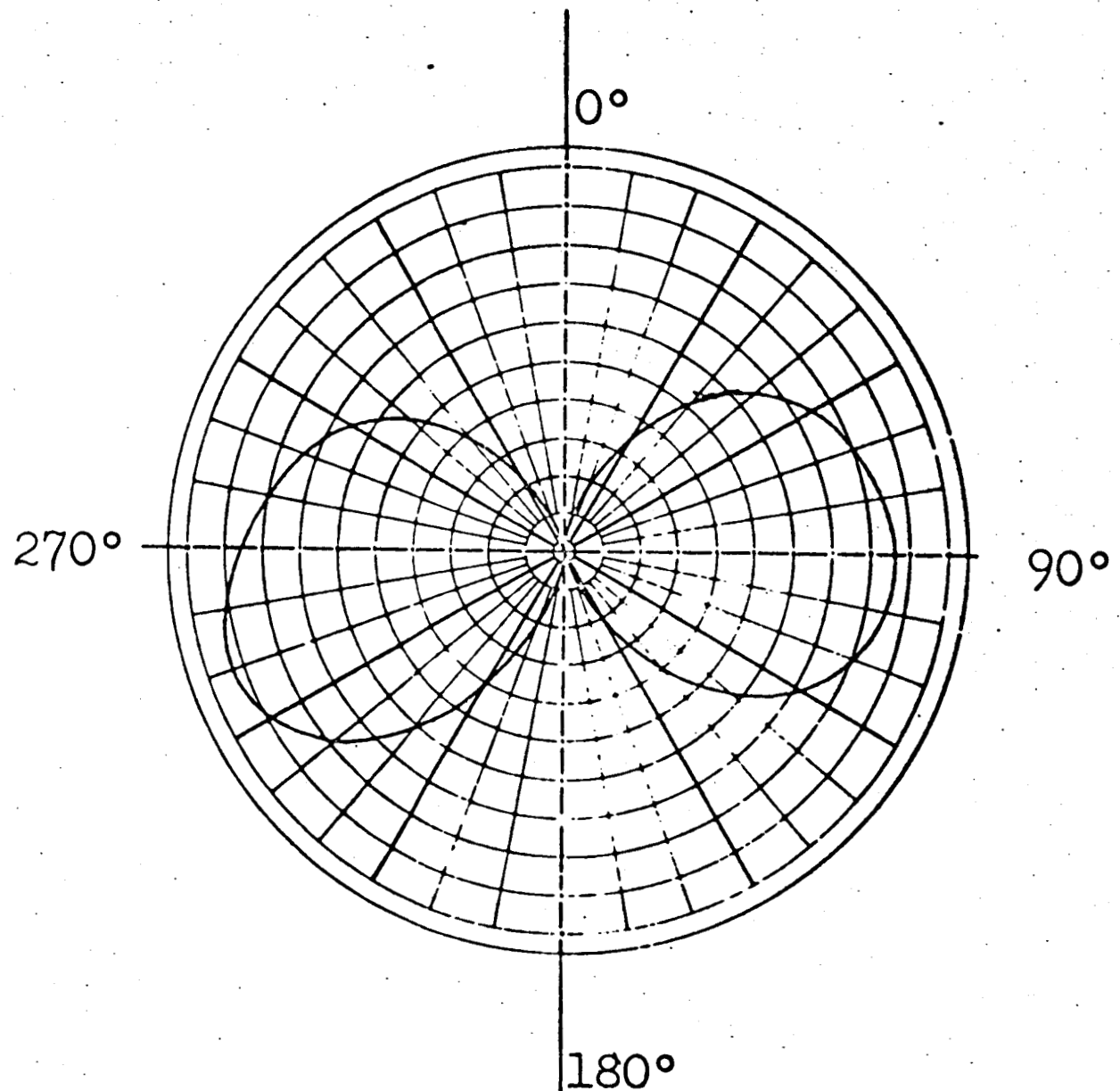
Figure 8

TRANSMIT DIPOLE PATTERN

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Figure 9

VHF Monopole Antenna Radiation Pattern

f = 150 mc

E_θ polarization

IV-H.   THERMAL CONTROL

     A passive thermal control system is employed for temperature control. However, in some cases special systems involving heaters are included. In general, slight modifications to the passive thermal control system have been required for each ERS flight, and an existing thermal analysis computer program has been designed and is used to help determine these modifications.

     Spacecraft temperature is based on a balance of heat generated within the spacecraft, heat absorbed from external sources (i.e., Sun and Earth), and heat emitted by the spacecraft. The resulting temperature can be perturbed by changing the spacecraft effective absorptivity. Absorptivity and emissivity are a function of the outside surface of the spacecraft.

     The majority of the outside surface of the octahedron is covered by solar cells with cover glass. The effective absorptivity is changed by appropriately selecting the thermal control materials covering the remaining surface of the spacecraft. Calculations for the eleven-inch octahedron, which have been reinforced by actual ERS program flight data, indicate that an average space-craft bulk temperature of approximately 15°C can be maintained, and that the average bulk temperature can be changed by approximately ± 8°C by appropriate selection of thermal control materials. Also the thermal time constant of a typical internal thermal mass of the spacecraft will be in the order of eight to sixteen hours. For example, data from the last eleven-inch ORS flight indicates that the bulk temperature of the spacecraft upon entering one eclipse was +14°C, and +11°C upon leaving the nine-minute eclipse. In general, the relatively small size of, and the use of good thermal coupling to the structure result in low thermal gradients throughout the spacecraft. In some cases, a small amount of insulation is sometimes required around such items as the battery system to maintain this at a slightly higher than ambient temperature and increase its thermal time constant.

     The existing thermal analysis computer program useful in determining modifications, can analytically test effects, such as varying the solar panel thickness on the temperature gradient of the spacecraft. Also, it can provide for the design of nonuniform thermal coating patterns in order to achieve localized thermal requirements if required.

Octahedral Research Satellite Mark II-B (ORS-II-B) - Zero Gravity
Heat Transfer Experiment - One 9" Octahedron flight vehicle and one prototype
vehicle are being designed under the same contract as ORS-II-A,
AF 04(611)-10747. The mission objective is to investigate the effects of near
zero gravity environments on heat transfer processes in a liquid. Basic data
will be obtained for the heat transfer regimes of natural convection, nucleate
boiling, and film boiling, and of critical heat flux levels. This will be a
subcooled, constant pressure experiment with special techniques applied to
maintain a constant degree of subcooling. A command-receiver will be
included to permit the experimenter to select any of a number of desired
heating rates for test in the orbiting laboratory. Preliminary design of
the spacecraft has been completed.

Octahedral Research Satellite Mark III (ORS-III) - One 11" Octahedron
was launched and one is being prepared for flight under Air Force contract
AF 04(695)-703. The primary purpose of these flights is to extend the loca-
tions and degree of radiation mapping. It is essentially an extension of the
earlier charged particle measurement program, but adds measurements from greater
altitude, covering several energy ranges, and will investigate gamma radiation
levels. The first flight will include five different radiation detection devices
including a Phoswich gamma counter; a geiger tube for very low energy electrons;
a silicon solid-state detector for medium energy electrons; a scintillation
detector for high-energy electrons, protons and gammas; and another scintillation
detector for lower energy protons and electrons. This larger spacecraft was
selected primarily to permit longer range or apogee telemetry transmission.
The larger solar panels permit increased transmitter power. The increased
volume also permits greater flexibility in radiation detector selection.
Spacecraft weight is approximately 17 pounds. After two months in orbit
the spacecraft performance is normal in all respects.

Solar X-ray Measurements - Two ERS satellites are currently being prepared
for a solar X-ray measurement mission under Air Force Contract AF 19(628)-5817.

Classified Program - Three ERS satellites are currently being prepared
for a classified mission.

V.   PAST FLIGHTS AND CURRENT PROGRAMS

Tetrahedral Research Satellite Mark I (TRS-I) - An Air Force contract
AF 04(695)-127 was undertaken to design, fabricate, and deliver a prototype
and nine flight units. These spacecraft were tetrahedra of 6.5 in. on a side,
weighing 1.5 lb. These small subsatellites were ejected from a Stage 2
vehicle in pairs and were to conduct independent experiments in the prescribed
orbit. The mission objective was to measure radiation damage to special
silicon solar cells with different types of solar cell shielding. Each space-
craft carried 112 n on p power solar cells plus 20 test cells. There was no
attitude stabilization, and each was designed to produce an almost constant
solar power supply of about 600 mw. A solid state analog telemetry system pro-
vided eight channels of data, five for the experiments, one for spacecraft
temperature, and two for telemetry calibrations. Each spacecraft carried
an end-of-life transistor timer designed to shut off telemetry transmission
after about four months. A total of four of the TRS spacecraft were success-
fully orbited and assigned international designations. The data from these
satellites have provided considerable information about radiation damage to
solar cells and have added to the understanding of the energy distribution and
intensity of space radiation.

Launches:	TRS No.	Frequency (mc)	International Designation
	1		1962 Alpha Chi II
	3 and 4	108.06/108.09	Did not orbit
	2 and 5	136.41/136.89	1963-14B/1963-14C
	7 and 9	136.89/136.41	Did not orbit
	10 and 11	136.89/136.41	1963-30B

TRS No. 11 did not separate from Stage 2 vehicle

Tetrahedral Research Satellite Mark II (TRS-II) - The TRS-II program
is under Air Force contract AF 04(695)-416 to deliver a prototype and three
TRS-II flight satellites. These satellites are to be placed in orbit as
subsatellites from Air Force vehicles. The purpose of the TRS-II is to
measure the intensity of charged particles throughout a large fraction of the
included volume of magnetosphere. The TRS-II, which is a 9" tetrahedron
weighing slightly over four pounds, separates from the Stage 2 vehicle and

performs radiation measurements independently of the main spacecraft systems. The experiments include omnidirectional radiation detectors with discrimination for electrons and protons. The radiation detectors were selected primarily to measure electrons at separate energy levels of greater than 0.5 Mev. Protons are measured at lower energy levels from greater than 10 Mev and less than 100 Mev. As of this date, two TRS-II satellites have been placed in orbit. Experimental data were acquired and are now in the process of being analyzed.

Launches:	TRS No.	Frequency (mc)	International Designation
	1	136.53	1963-39B
	2	136.77	1964-40C

Octahedral Research Satellite Mark II (ORS-II) - Two flight type satellites are currently being developed and fabricated for this program under Air Force contract AF 04(611)-9883. This spacecraft has been designed to provide measurements of surface contact bonding under the deep vacuum conditions of space. The mechanisms employed for making these measurements are a number of typical propulsion system valves containing various test materials as poppets and seats, and a special contactor unit which cyclically contacts a number of material combinations exposed to the vacuum of space. This program is nearing flight phase.

Octahedral Research Satellite Mark II-A (ORS-II-A) - Friction Experiment - One 9" Octahedron flight vehicle and one prototype vehicle are being designed in this program under Air Force contract AF 04(611)-10747. The mission objective is to investigate the effects of the space environment, particularly deep vacuum, but also radiation, on surface friction characteristics of materials. Sixteen different material combinations will be extended from the spacecraft for maximum exposure and relative motion imposed. A command-reciever is being included for the experiment, primarily to minimize the effects of wear on the frictional surfaces and to give greater flexibility to the experimenter. In normal operation, motion will occur only while the satellite is in communication with the ground tracking station and at the discretion of the experimenter. Preliminary design of the spacecraft has been completed.